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LIME USE IN WASTEWATER TREATMENT

DESIGN AND COST DATA

BROWN AND CALDWELL

PREPARED FOR
MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY

OCTOBER 1975

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This report presents design and cost information on lime use in wastewater treatment applications. It includes design and cost information on lime handling, liquid processing, solids generation and dewatering, lime recovery and ultimate ash disposal. The report takes a design manual approach so that the information presented has maximum usefulness to environmental engineers engaged in both the conceptual and detailed design of wastewater treatment plants.

Design data on alternate sludge thickening and dewatering processes are presented with special emphasis on wet classification of calcium carbonate from unwanted materials and on maximizing the dewatering of wasted solids.

Alternative recalcining techniques are assessed and problem areas identified. A relatively new technique for beneficiation of the recalcined product is presented. Approaches to heat recovery are presented that minimize the net energy requirements for recalcination and incineration.

A computer program for computation of solids balances is included as a design aid and two case histories are presented which portray the cost of lime treatment, sludge processing and lime reclamation.

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This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise, and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The Municipal Environmental Research Laboratory contributes to this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The research reported here was performed for the Ultimate Disposal Section of the Wastewater Research Division to provide design and cost data on lime use, reuse, and recovery in wastewater sludge handling and disposal operations. The information presented in this report is of immediate use to the treatment plant designer and should make possible improved operation as well as operation at a reduced cost.

ABSTRACT

This report presents design and cost information on lime use in wastewater treatment applications. It includes design and cost information on lime handling, liquid processing, solids generation and dewatering, lime recovery and ultimate ash disposal. The report takes a design manual approach so that the information presented has maximum usefulness to environmental engineers engaged in both the conceptual and detailed design of wastewater treatment plants.

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A computer program for computation of solids balances is included as a design aid and two case histories are presented which portray the cost of lime treatment, sludge processing and lime reclamation.

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SECTION I

CONCLUSIONS

The purpose of this report is to present design and cost information on lime handling, liquid processing, solids generation and dewatering, lime recovery and ultimate ash disposal. Since the report takes a design manual approach rather than a research investigation approach, the conclusions are of a different nature than those which would normally be found in most Office of Research and Development reports. The following conclusions were drawn:

1. Lime treatment of raw sewage is an attractive process with many advantages, has wide applicability, is state-of-the-art technology and should be evaluated in the selection procedure of treatment alternatives.

2. The choice of coagulants to be used in waste treatment processes should be based on cost and performance comparisons. The selection process should consider both chemical costs and the costs of sludge processing, as considerable savings can be made by careful choice of operating pH and supplemental metal salts for coagulation.

3. Combined sludges generated by lime coagulation in a chemical primary sedimentation tank can be effectively wet classified into two components with a solid bowl centrifuge. One component, the cake, contains the bulk of the calcium carbonate and silica. The other component, the centrate, contains the bulk of the organics and other chemical precipitates. Wet classification produces a cake ideal for recalcination, as it is high in calcium carbonate and low in moisture content.

4. Sludge handling processes incorporating wet classification are more effective in reducing the total water to be evaporated in furnaces than processes not employing wet classification.

5. Sludge handling processes incorporating wet classification coupled with pressure filtration of the centrate are less costly than processes where whole sludge recovery is practiced.

6. Lime recovery through recalcination can produce a readily reusable quicklime that can significantly reduce chemical costs in larger plants.

7. The multiple hearth furnace (MHF) is well established in the wastewater sludge recalcination field as a result of operational experience with tertiary lime sludges and large-scale recycling tests with raw wastewater lime sludges. The fluidized bed reactor (FBR) has been used in similar applications, but operating experience has not yet been obtained in the wastewater field. Developmental work will have to be done to establish the FBR as a working tool. The rotary kiln needs substantial research and development work before it can be applied with confidence to wastewater sludge applications.

8. When applied with energy recovery features, both the MHF and the FBR can be competitive, on an energy basis, with the industrial production of lime from limestone.

9. Recalcined lime applied in the primary sedimentation process causes more complete phosphorus removal and improves the softening reactions when compared to the use of "new" lime alone.

10. Sludge handling processes incorporating wet classification recycle substantially less unwanted solids than processes not employing wet classification.

11. When centrifugation and pressure filtration are used, the use of recalcined lime has been shown to improve the dewatering of waste sludges generated in lime treatment.

12. When centrifuges are used for wet classification or whole sludge recovery, dry classification of the recalcine furnace product is essential for controlling the level of silica in the system. High levels of silica recycle cannot be tolerated due to centrifuge wear.

13. Relative effectiveness of the alternative dewatering processes for the centrate from the wet classification step are as follows: pressure filtration, vacuum filtration and centrifugation. However, vacuum filtration rates are low and the cake does not separate easily from the septum.

14. As a rule, the pH of operation of the chemical primary tank must be considerably in excess of pH 9.5 to generate enough calcium carbonate to justify lime recovery.

15. Low lime treatment plants are considerably less efficient in phosphorus and organic removal than either high lime treatment plants or plants incorporating the use of lime with other metal salts.

16. Flocculation pH influences the dewatering processes significantly. A pH greater than 11.0 adversely affects the dewatering of the wet classification centrate. Higher filter yields on nonclassified whole sludges are obtained with high pH sludges (pH >11.5) than with low pH sludges (pH < 11.5).

17. Rectangular sedimentation tanks incorporating preaeration for grit removal and flocculation are lower in capital cost than circular tanks with separate grit removal.

18. The quantity of sludge produced where lime is used in a primary sedimentation tank can be accurately estimated by high-speed digital computation.

SECTION II

RECOMMENDATIONS

1. The Energy Crisis has brought to the forefront the need for consideration of the impact that the choice of a particular treatment process has on energy demands. Rapid application and development of the use of heat recovery in incineration systems is justified. The full economic and environmental benefits of such applications should be investigated.

2. Lime treatment is not a new-untried technology; the environmental engineering profession should adopt it as one of its standard techniques.

3. As lime treatment techniques advance in their development, this development should be documented to expand the data base, especially in the areas of economics and long-term plant operating data.

SECTION III

INTRODUCTION

Increasingly, waste treatment systems are being designed to produce effluents of substantially higher quality than can be obtained by conventional primary or secondary processes. These new, "advanced waste treatment" systems are oriented toward the removal of sewage constituents which are not significantly removed by conventional treatment processes. These advanced waste treatment systems often incorporate the addition of coagulant chemicals for enhanced phosphorus, solids, grease or heavy metals removal. Coagulant chemicals that are commonly in use today include iron (ferrous or ferric), aluminum (alum or sodium aluminate), and calcium (lime).

Lime is an attractive chemical for utilization in advanced waste treatment systems, and has been selected as the chemical of choice in a number of situations. In some locales lime costs may be lower than either aluminum or iron compounds, and lime sludges are generally easier to dewater than ferric and alum sludges. The use of lime allows higher surface overflow rates on sedimentation tanks than does an iron or aluminum salt, and this is an important factor for upgrading existing treatment plants. In all cases, however, coagulant choice should be based on an engineering economic evaluation of each alternative.

Lime was used in waste treatment long before the present era of "advanced waste treatment" (AWT). An example of this was the Laughlin Process, which was used during the 1930's and employed lime in a first stage system followed by ferric chloride in a second stage. Chemical treatment was considered a competitive process to biological treatment in the 1920's and early 1930's but was supplanted in later years by refinements of the activated sludge and trickling filter processes which seemed to be more promising for strictly BOD removal.

Interest in lime treatment rekindled in the 1960's when environmental concern began to be expressed about other sewage constituents such as phosphorus, heavy metals and viruses. This concern spawned the present AWT era in the technology of sewage treatment. The use of lime in the treatment scheme enhances removals of phosphorus, metals and viruses over that obtained by conventional primary and biological treatment schemes.

Initial full-scale applications of lime treatment in the AWT era were so-called "tertiary" applications and followed conventional biological treatment. An example of such a practice is at South Lake Tahoe. Generally, these applications were primarily intended for phosphorus removal, but heavy metals, suspended solids and virus removals were also obtained. In the particular case of South Lake Tahoe, pH elevation for ammonia stripping was also desired. Some of the later applications of lime in AWT have integrated lime precipitation into an earlier stage, the primary stage of the treatment system. In terms of historical perspective, this could be considered a partial reversion to the chemical treatment systems of the 1920's and

1930's. The main difference is that downstream processes normally polish the chemical primary effluent. The advantage gained from moving lime forward from the tertiary stage is that one or more treatment stages can be eliminated, making the overall treatment system less complex.

PURPOSE AND SCOPE

This report is basically concerned with the design of treatment facilities where lime is incorporated in the primary stage of treatment. Tertiary applications have been well documented in the literature. Examples of primary stage applications are:

1. Low level lime addition into the primary for phosphorus removal followed by biological treatment for organic reduction.
2. Moderately high level lime addition into the primary for organic reduction to permit nitrification in a biological treatment step.
3. Lime addition into the primary, followed by filtration and activated carbon adsorption.
4. Lime addition into the primary for improved organics, grease, and heavy metals removal, followed by ocean disposal of the lime clarified effluent.

This review presents design and cost information on lime handling, liquid processing, solids generation and dewatering, lime recovery and ultimate disposal.

BACKGROUND

Much of the information contained in this manual has been derived from the experience of Brown and Caldwell, of Walnut Creek, California and Caldwell Connell Engineers of Melbourne, Australia, gained in the design of four treatment plants which will employ lime in the primary stage of treatment. Two of these plants, the Central Contra Costa Sanitary District (CCCSD) plant and the City of Livermore plant, are located in the State of California and are oriented towards water reclamation. Two other plants, Canberra and Darwin, are located in Australia and are oriented towards water pollution control. Practical operating experience has been gained in full-scale operations in conjunction with the CCCSD at the CCCSD Advanced Treatment Test Facility (ATTF)[1,2] where chemical primary flows average up to 2.5 mgd. Full scale liquid and solids processing studies have been conducted at the ATTF. Additional information was compiled from the literature covering lime use in water and wastewater treatment, manufacturers data and information data supplied by the Environmental Protection Agency, and from site visits made during the project. These sources are specifically referenced where used and summarized in the acknowledgments section.

REFERENCES

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2. Parker, D.S., K.E. Train and F.J. Zadick. Sludge Processing for Combined Physical-Chemical-Biological Sludges. Environmental Protection Agency. Washington, D.C. Report No. EPA-R2-73-250. July, 1973, 141 p.

SECTION IV

FUNDAMENTALS OF LIME

DEFINITIONS

Lime is a general term applied to several chemical compounds that share the common characteristic of being highly alkaline. In the water and wastewater treatment fields, the term is usually applied to quicklime and hydrated lime. Both types of lime are frequently used and are readily available throughout the United States. The definitions given below are intended to clarify the confusing terminology often found when dealing with different forms of lime. Standard definitions used in the industry follow.

Limestone is the basic compound from which usable lime forms are derived. There are two kinds of limestone: (1) high calcium limestone which is almost entirely calcium; and (2) dolomitic limestone which is a double carbonate mineral of calcium and magnesium containing 35 to 45 percent of the latter, expressed as magnesium oxide.

Quicklime is derived from high calcium limestone by a high temperature calcination process. Quicklime contains about 90 percent calcium oxide, and for this reason is also called calcium oxide. Two other terms sometimes applied to quicklime are burned lime and unslaked lime. Quicklime does not react uniformly when applied directly to water or wastewater but must first be converted to the hydrate $Ca(OH)_2$.

Hydrated lime or slaked lime is a dry powder obtained by a chemical reaction that occurs when sufficient water is added to quicklime to satisfy its affinity for water. This form of lime is also referred to as hydrate. The chemical composition of hydrated lime depends on the calcium oxide content of the quicklime from which it is derived. A high calcium quicklime will provide a high calcium hydrated lime containing 72 to 74 percent calcium oxide and 23 to 24 percent water of hydration.

Pebble or crushed lime is the most common form of quicklime, and the effective diameter of the pebbles varies from about 1/4-inch to 2 inches. This lime is produced mostly in rotary kilns.

Lump lime is the product whose pebbles or lumps range in effective diameter from eight down to two or three inches. Lump lime is produced in stationary vertical kilns and is crushed after burning.

Recalcined lime is the product recovered after burning lime sludge from a water softening or wastewater plant. Calcination takes place in a rotary kiln or any of several types of furnaces available in the industry. (See Section IX).

So far, no standard specifications have been issued for lime to be added to wastewaters. American Water Works Association (AWWA) Standard B202-54, for quicklime used in water works, can be followed when specifying lime for wastewater treatment. Tables 4-1 and 4-2 summarize the main characteristics of lime chemicals in general, and of quicklime in particular.

LIME IN WASTEWATER TREATMENT

Chemical treatment of municipal wastewaters has been practiced for almost a century. It is usually employed as a simpler and more flexible alternative to secondary biological processes, although it is not as effective in removing soluble organic matter. While chemical treatment has never been widely practiced, it was found particularly useful when colloidal solids and finely divided suspended matter could not be removed by plain sedimentation, and coagulants had to be added to the wastewater. Chemical treatment has found its widest application in the treatment of industrial wastes, where its flexibility, lower cost and simplicity of operation and maintenance were all attractive assets to industry. The fact that some trade wastes are either not amenable to biological treatment or toxic to the microorganism population has also contributed to the wide application of chemical treatment in the industrial wastes field.

The advent of AWT processes has brought a new popularity to chemical treatment. The inability of conventional biological treatment to effectively remove nutrients, i.e., nitrogen and phosphorus, and other organic and inorganic pollutants, paved the way for physical-chemical-biological treatment. These combined processes have put the goal of wastewater reclamation and reuse well within the confines of present day technology. The use of lime as a coagulant in AWT is due to its well established efficacy in removing phosphorus from raw wastewaters. Additional benefits derived from lime coagulation in the primary treatment stage include the increased removal of organic matter, which decreases the organic load on subsequent biological processes; the enhanced removal of heavy metals and viruses; and, as the pH value is raised above 9.5, precipitation of magnesium as magnesium hydroxide. The addition of lime to raw wastewater is treated in detail in Section VI.

LIME SLAKING

Slaking is a chemical process which makes quicklime reactive in water and wastewater. "Slaking" and hydration are synonymous terms from a chemical standpoint. As used in the lime industry, however, slaked lime is hydrated quicklime containing considerable excess water. In contrast commercial hydrated lime is a dry, ultrafine white powder, more concentrated than aqueous forms of slaked quicklimes; however, chemically both are the same, i.e., hydroxides.

Table 4-1. CHARACTERISTICS OF LIME CHEMICALS[1]

Chemical	Shipping data		Physical and chemical characteristics			
Common name Formula	Available forms	Containers and requirements	Appearance and properties	Weight lb./cu. ft.[2] (bulk density)	Commercial strength	Solubility in water g/100 ml. @ 25°C
Quicklime CaO	Pebble Crushed Lump Ground Pulverized	Moisture proof bags - 80-100 lb.; wood bbl.; bulk - C/L. Store dry max. 60 days; keep container closed.	White (light grey, tan) lumps to powder. Unstable, caustic irritant. Slakes to hydroxide slurry evolving heat. Air slakes to $CaCO_3$. Sat. Sol. pH 12.4	55 to 75 To calculate hopper capacity - use 60: Sp.G., 3.2-3.4	70 to 96% CaO (Below 88% can be poor quality)	Reacts to form $Ca(OH)_2$. Each lb. of quicklime will form 1.16 to 1.32 lb. of $Ca(OH)_2$, with 2 to 12% grit, depending on purity.
Recovered lime CaO	Pellets	Bulk delivery direct from kiln to storage bin	Light grey, tan Same properties as quicklime		75 to 90% CaO	Same as quicklime
Dolomitic lime CaO · MgO (MgO content varies)	Pebble Crushed Lump Ground Pulverized	Bags, 50-60 lb.; bulk - C/L; bbl.	Same appearance and properties as quicklime, except MgO slakes slowly	Pebble, 60-65 Ground, 50-75 Lump, 50-65 Powder, 37-63, Avg. 60 Sp.G., 3.2-3.4	CaO - 55 to 57.5%; MgO - 37.6 to 40.5%	Slakes to form $Ca(OH)_2$ slurry plus MgO, which slakes slowly
Hydrated lime $Ca(OH)_2$	Powder (Passes 200 mesh)	Bags - 50 lb.; Bbl. - 100 lb.; Bulk - C/L (Store dry)	White, 200-400 mesh; powder free of lumps; caustic, dusty irritant; absorbs H_2O and CO_2 from air to form $Ca(HCO_3)_2$. Sat. Sol. pH 12.4	35 to 50 To calculate hopper capacity - use 40; some 20 to 30 - use 23; Sp. G., 2.3-2.4	$Ca(OH)_2$ - 82 to 98 %; CaO - 62 to 74% (Std. 70%)	0.18 @ 0°C 0.16 @ 20°C 0.15 @ 30°C 0.077 @ 100°C
Carbide lime $Ca(OH)_2$	Powder 70 - 90% (200 mesh) Slurry	Bulk	Coarse, grey powder; grey slurry (35% solids)	35 to 55	95% $Ca(OH)_2$	Same as $Ca(OH)_2$
Dolomitic hydrated lime $Ca(OH)_2 + Mg(OH)_2$	Monohydrated powder slaked at atmos. press. Dihydrate powder slaked at high press. and temp.	Bags - 50 lb.; Bbl. Bulk - C/L (Store dry)	Tan to white powder free of lumps (-200 mesh); caustic, dusty irritant; Sat. Sol. pH 12.4	Monohydrate 25 to 37; Dihydrate 27 to 43; To calculate hopper capacity - use 40; Sp.G., 2.65-2.75	Monohydrate $Ca(OH)_2$ - 62% MgO - 34%; Dihydrate $Ca(OH)_2$ - 54% $Mg(OH)_2$ - 42% (approx.)	Same as $Ca(OH)_2$
Limestone (unburned lime) $CaCO_3$	Powder Granules Ground	Bags - 50 lb.; 80 lb. 100 lb. drums; Bulk - C/L	White amorpnous powder; Sat. Sol. pH 9 - 9.5	Powder, 35-60; Granules, 100 - 115; Sp.G., 2.65-2.75	96 to 99%	0.0013 @ 20°C 0.002 @ 100°C
Dolomite $CaCO_3 \cdot MgCO_3$	Lump or crushed Ground Powder	Bags - 50 lb.; Drums Bulk - C/L	White, grey, tan; Sat. Sol. pH 9 - 9.5	87 to 95; Sp.G., 2.8-2.9	Varies	Approx. same as limestone

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[1] Reproduced by permission of BIF, a Unit of General Signal Corporation.

[2] 1 lb/cu ft = 16 kg/cu m

Table 4-2. CHARACTERISTICS OF MAIN GRADES OF QUICKLIME*

Grades	Calcium content	Form	Particle size
High calcium	>88% CaO	Lump	3" - 8" and smaller
Medium calcium	75 - 88% CaO	Lump crushed	1/2" - 2 1/2" to dust
Low calcium	<60 - 76% CaO	Pebble	1/4" - 1 1/2" and smaller to dust
Dolomitic	51 - 58% CaO 35 - 41% MgO	Pellet	20 to 100 mesh
Magnesium	5 - 35% MgO	Ground	-8 to -100 mesh
Dolomitic lime could also be classed as a low calcium lime.		Pulverized	+100 to -200 mesh

Burned or calcined	Calcination temperature degrees F	Slaking characteristics[2]
Soft	Calcined just above the decomposition temperature necessary--1,800 to 2,400°F in a minimum time.	Very quick slaking and temperature rise
Normal	Calcined at about 2,400 to 2,600°F in a minimum time.	Fast to medium slaking and temperature rise
Over	Calcined at 2,500 to over 2,600°F. If lower, then time would be longer.	Medium to slow slaking and temperature rise
Hard	Calcined above 2,600°F. If at a lower temperature, time would be longer.	Slow to very slow slaking and temperature rise

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[2] Time of calcination, type of kiln, composition of limestone and the composition of the surrounding atmosphere (CO_2 content in kiln), are all factors in the type of burned lime produced, as to reactivity, etc. At a lower ratio (say 2.5 - 1) reaction could be quicker or at least similar. Air slaking will increase slaking time and decrease the temperature rise.

Depending upon the proportions in which quicklime and excess water are combined, the hydration process can yield a milk-of-lime, a lime slurry, or a viscous lime paste of varying degrees of consistency. As will be seen later, the different types of slaked lime lend their names to the mechanical equipment used to mix quicklime and water. Predictably, this type of equipment is called a lime slaker and it is described in Section V.

Lime slaking provides two available hydroxyl ions that react readily. The process is exothermic, i.e., appreciable heat is emitted during the chemical reaction. The progression from limestone to slaked lime is shown below.

Calcination

Limestone	$CaCO_3$
+	+
Heat	Δt
↓	↓
Carbon dioxide	CO_2
+	+
Quicklime	CaO

Slaking (Hydration)

Quicklime	CaO
+	+
Water	H_2O
↓	↓
Slaked lime	$Ca(OH)_2$
+	+
Heat	Δt

Several variables influence the required slaking time and quality of the resulting hydrated lime. The National Lime Association lists the following:

1. Reactivity of the quicklime: whether the quicklime is hard, soft, or medium burned will influence the speed of slaking and temperature attainment.

2. Particle size and gradation of quicklime: whether the quicklime is lump, pebble, ground, pulverized, or run-of-the-mill gradation is important. The finer sizes of the same quality slake most rapidly.

3. Optimum amount of water: whether too much or too little water is used. Limes vary in their optimum water: lime ratio.

4. Temperature of water: whether slaking water is too cold or possibly too hot (steam) for the particular slaking conditions can affect the product. Slow reacting limes need heated water; reactive limes do not.

5. Distribution of water: the manner in which water is introduced into the slaking chamber is a factor, and an even flow is desired.

6. Agitation: too vigorous or insufficient agitation of quicklime and water is undesirable. Some agitation is necessary.

The standard tests to determine the optimum slaking conditions for a given type of quicklime are AWWA B-202-65 and ASTM specification C110 on Physical Tests of lime. The reactivity of quicklime in water is expressed as the number of minutes required for a temperature rise of 40 degrees Centrigrade (104 F). Reactivity is classified as follows:

> High-reactivity lime will show a 40 C temperature rise in 3 minutes or less and will complete the reaction within 10 minutes.
>
> Medium-reactivity lime will show a 40 C temperature rise in 3 to 6 minutes and will complete the reaction in 10 to 20 minutes.
>
> Low-reactivity lime will require more than 6 minutes to show a 40 C temperature rise and will require more than 20 minutes to complete the reaction.

Under AWWA B-202 the particular quicklime will be rejected if the sample tested fails to produce more than a 10 C (50 F) rise in temperature in 3 minutes or fails to reach the maximum temperature in 20 minutes when slaked under test conditions. It should be pointed out that these rules are applicable to commercial grades of quicklime and are not intended to cover recalcined limes. The standard test has aroused considerable controversy. A leading manufacturer of paste-type slaking equipment has the following comments:

> "This test is intended to predict the slaking characteristics of quicklime. It is obviously slanted toward the slurry slaker approach, as it uses a 4:1 water:lime ratio. We question its value. As an example, an oyster-shell lime barely qulified as a low-reactive lime. When the water was reduced to a 2:1 ratio, it qualified as a medium-reactive lime. When repeated at 120 F, it reacted almost violently. This same lime is being successfully slaked in a paste slaker."

The effect of water temperature and water-lime ratios on the slaking process will be further discussed when describing lime slakers in (Section V).

SELECTION OF LIME

As mentioned earlier, quicklime and hydrated lime are frequently used in water and wastewater treatment. Which type to use in a particular situation is influenced by a number of factors, such as scale of operation, method cost, transportation cost, and availability. Material cost depends on whether bagged or bulk lime, hydrated or quicklime is used. The choice between purchasing lime in bags or in bulk is a direct function of rate of use. Where chemical requirements are small, bagged lime is preferred. Conversely, at the larger treatment plants it is more efficient and economical to handle bulk lime. More details about lime delivery and handling will be given in the next chapter.

The selection of quicklime or hydrated lime also depends on economics and availability. The cost of hydrated lime is about 30 percent greater than the cost of a quicklime with the same calcium oxide content. The difference is due to the higher production cost of the former and to higher transportation charges; on the other hand, the capital cost of the slaking equipment required when quicklime is used, will tend to offset the savings in material cost. The source of supply and its relation to transportation costs also play an important role in determining whether quicklime or hydrated lime should be selected. Other factors to consider are storage space available at the treatment plant, plant process layout in relation to storage location, material handling problems, and the storage requirements of the two types of lime.

In analyzing the factors discussed above, the National Lime Association offers the following comments:

1. Where lime consumption is small, such as 50 to 1,000 lb/day, i.e., 1 to 20 50-lb bags, bagged hydrated lime is clearly indicated. Probably this limit could be extended to 1,500 lb/day, but at this point, if lime is being consumed seven days a week, consumption will reach 22½ tons/month. Then, the economy of truck load bulk shipments of 15 to 20 tons starts to become attractive. But then bulk silo storage and unloading facilities may have to be purchased and installed. If headroom is unavailable for a silo and there is ample ground floor space for storing bags, then the use of bagged hydrate may be justified up to 2,000 lb/day or even more.

2. With respect to bulk lime, hydrate is generally indicated up to 3 to 4 tons/day (100-125 ton/month) over quicklime. At this point the inherent economy of quicklime, in spite of slaking expense, should be considered. Again, due to peculiar plant conditions the use of hydrate up to 200 tons/month may be warranted; however, above this figure it is quicklime's province. Many of those plants that use quicklime in the lower ranges suggested for hydrate may be saving little or nothing due to greater losses of lime through air slaking and recarbonation. This is particularly true if the quicklime is highly reactive, of small particle size, and is used under humid conditions. Hydrate is more stable and stores better.

As is the case with most engineering decisions, selection of the type of lime to be used should be based on a detailed economic analysis, taking into account all the factors just mentioned. Table 4-3 summarizes the characteristics of quicklime and hydrated lime.

Table 4-3. CHARACTERISTICS OF QUICKLIME AND HYDRATED LIME

	Quicklime	Hydrated Lime
Formula	CaO	$Ca(OH)_2$
Molecular Weight	56.1	74.1
Physical State	White solid	White solid
Particulate Size	Pulverized to lump	Power, 200 to 400 mesh
Bulk Density, lb/cu ft	55 to 75	35 to 50
Specific Gravity	3.2 to 3.4	2.3 to 2.4
Affinity for Water	Reacts quickly to form $Ca(OH)_2$ with heat of formation, 490 Btu/lb.	Absorbs H_2O and CO_2 from air to form $CaCo_3$
Solubility	Slightly, varies inversely with temperature	Slightly, varies inversely with temperature
Stability in Bagged Storage	In multiwalled bags, max. 60 days	Up to 6 months,in dry tight bags
pH of Saturated Solution	12.4	12.4

SECTION V

HANDLING OF LIME

LIME DELIVERY

Lime can be delivered either in bags or in bulk. The choice between these two forms depends mostly on the rate of chemical use at the treatment plant. Bagged lime is delivered in truck or rail car. Once at the treatment plant, the bags are transferred by hand truck, fork lift, or overhead crane to storage. When a large number of bags are used, it is advantageous to purchase lime in palletized shipments and use fork lift trucks to take the pallets to storage. In addition to saving space and labor, this procedure also minimizes bag breakage. Other methods of handling bagged lime will be reviewed when discussing in-plant transport practices. When lime use justifies bulk shipments, delivery can be made by using covered hopper railroad cars, container and box cars, and a variety of specially designed trucks. Bulk delivery offers many advantages: lower initial cost; faster unloading; reduced labor cost for handling; elimination of losses due to torn bags and spillage; and improved safety, operating, and housekeeping conditions.

The method of transport to the plant is based primarily on economics. When railroad access is feasible and the rate of use justifies the cost of railroad siding and unloading facilities, delivery by rail is usually cheaper since a railroad car has three times the load carrying capacity of a bulk truck. The CCCSD water reclamation plant[1] includes a complete in-plant railroad system connected to the Atchison, Topeka and Santa Fe railway mainline. Three chemical unloading platforms are being provided to unload lime, chlorine, ferric chloride, methanol, and carbon dioxide.

Where a railroad siding is not practical or the distance from the shipping point is relatively short, a trailer truck is a fast and economical way to deliver bulk shipments. Unlike rail cars, trucks can have access to nearly all areas within the treatment plant; therefore, there is more flexibility in selecting the location for storage. Also, the length of unloading lines can be kept at a minimum by parking trucks close to the storage facilities. The pneumatic truck is available in two basic designs. The more widely used is the self-unloading type, in which conveying air is supplied by a positive displacement blower mounted on the trailer. Lime is blown from the truck directly to storage through a 4-inch pipeline. The second type of pneumatic truck requires an external souce of compressed air, or a separate mechanical conveyor system, to transfer lime to storage. Blower trucks are available in capacities varying from 20 to 36 cu m (700 to 1,300 cu ft). The latter can deliver up to 20 tons of hydrated lime and 24 tons of quicklime.[2] The larger capacities are accommodated by dividing the trailer into compartments, each provided with a sloping or hoppered bottom to facilitate material outflow. Further details on truck design an available in the literature.

LIME UNLOADING AND STORAGE

Unloading bagged lime is a simple operation and was previously described under Lime Delivery. The following storage precautions are recommended by the National Lime Association:

> "Storage areas for bagged materials must be covered to prevent rain from wetting the bags. Hydrated lime is normally packed in multiwall paper bags which are not resistant to free water or humid air. Quicklime is also packaged in multiwall paper bags, one or more of the plies moisture proofed. This moisture proofing is effective in preventing the entrance of humid air but is not usually designed to be effective against liquid water. This is particularly true at the valve where humid air or liquid water may enter more readily and start slaking the lime; and the heat and swelling will cause the bags to burst. Hence, quicklime storage must be designed to avoid any accidental contact with water. As an example, in one storage warehouse, a good tight roof was provided, but the bags were stored close to the door. This door was inadvertently left open a few inches during a driving rain which wetted the bags at the bottom of the pile. These broke open and the pile collapsed, resulting in an expensive clean-up operation together with considerable loss of lime. Because of the heat generated in accidental slaking of lime, bagged quicklime should never be stored adjacent or too close to combustible materials."
>
> "Hydrated lime may be stacked as much as twenty bags high without injuring the bottom bags (higher when palletized). In dry storage, hydrate may be stored for periods up to one year without encountering serious deterioration. When stored for extended periods, a slight increment of carbon dioxide may be found at the corner of the bag near the valve. This carbonation during storage is usually evident only after storage for at least six months and then does not penetrate more than about one-half inch into the bag near the valve."
>
> "Quicklime will deteriorate in storage at a much more rapid rate than hydrated lime. Under good storage conditions, with multiwall moisture proofed bags, quicklime may be held as long as six months, but in general should not be stored over three months. Care should be exercised to use the material in the order it is received, rather than maintain an inactive reserve stock which may not be consumed for several months."

Bulk shipments of lime can be unloaded from rail cars or trailer trucks by mechanical or pneumatic equipment. The latter method has gained wide acceptance because of its simplicity and high unloading speed. Either system can be used to unload lime when effective particle diameters are smaller than 2½-inch (6.4 cm) but 1¼-inch (3.2 cm) or smaller is preferable for efficient pneumatic conveying.[2]

Mechanical handling usually involves several steps. Lime is first transferred from delivery car or truck into a receiver hopper. From this hopper, some type of conveyor (screw, belt, etc.) is used to feed the material to the elevating equipment (bucket elevator, screw-lift, etc.) which finally discharges it into the storage bin or silo. The basic equipment can be arranged in a variety of ways to suit each particular situation, e.g., an inclined screw conveyor can be used to transfer lime directly from receiving hopper to storage bin when headroom is available and the silo is of limited height. Table 5-1 gives information published by the National Lime Association for preliminary sizing of mechanical conveyors and elevators. Mechanical handling of lime will be discussed in more detail under In Plant Transport Methods.

Table 5-1. SIZING DATA FOR SCREW CONVEYORS AND BUCKET ELEVATORS

Screw Conveyor Data

Screw size (inches)	Normal rpm	Tons quicklime (per hour)
6	50	2 - 2-1/2
9	50	7 - 8
12	50	15 - 20
16	50	45 - 50

Bucket Elevator Data

Bucket size (inches)	Bucket spacing		Speed		Tons quicklime (per hour)
	cm	inches	m/min	ft/min	
6 x 4	33	13	69	225	8 - 10
8 x 5	41	16	70	230	15 - 20
10 x 6	46	18	82	270	30 - 35
12 x 7	46	18	93	305	58 - 65
14 x 7	48	19	110	360	50 - 60

Lime unloading which uses pneumatic conveying equipment usually results in a simpler and more flexible arrangement than that obtained by mechanical conveyors. Dusting, a common occurrence around lime unloading operations, is reduced to a minimum and can be completely eliminated where a negative pressures system is used. These advantages have to be weighted against greater power requirements for pneumatic than for mechanical conveying systems of equal capacity. Safety considerations also favor the pneumatic approach, since there are no moving parts and, therefore, no risk of injury to the operator. The pneumatic conveyor transports material in suspension by means of a high velocity air stream. For quicklime and hydrated lime, this velocity varies from 914 to 1520 meters per minute (3,000 to 5,000 fpm). The higher values are required to blow quicklime because of its higher bulk density (880-960 kg/cu m or 55-60 lb/cu ft) than pebble quicklime bulk density (400-560 kg/cu m or 25-25 lb/cu ft) for hydrate.

Two types of in-plant pneumatic systems are commonly used to unload dry chemicals: negative pressure (vacuum) and positive/negative pneumatic conveyors. The equipment is commonly provided as a package. The lighter units can be mounted on skids, casters, or wagon type trailers when the application calls for a portable unit. The higher capacity unloading systems are normally stationary. The negative pressure unloading system consists of an intake nozzle, a receiver-separator, a vacuum pump, accessories, and interconnecting piping.

To unload a rail car or truck, the intake nozzle is attached to the vehicle hoppers through quick-opening couplings. The intake assembly is usually mounted on a skid base to facilitate handling. Lime is drawn directly into the conveying line by air flow under the suction created by the vacuum pump. The air stream then conveys the fluidized material to the receiver-separator (usually a bag-type filter). In the filter receiver lime separates from the air by cyclonic action, drops to the cone shaped bottom and is discharged to the storage silos through a rotary valve feeder. Conveying air is cleaned as it flows through the filter bags and, after passing through the vacuum pump, is exhausted to the atmosphere.

Vacuum systems are limited to operating pressures of 25 to 30 cm of (10 to 12 in.) Hg below atmospheric pressure and by the number of storage bins which can be filled from a single receiver-separator. When pressure losses exceed 30 cm (12 in.) Hg, or when lime is stored in a large number of silos, a positive/negative pneumatic conveyor is required.

Positive pressure conveyors are normally used when material must be delivered to several separated storage bins located at considerable distances from the delivery station. In a positive pressure system, the conveying stream is created by the air discharged from a blower, and this air "pushes" the solids through the conveying line. Normally, a rotary positive displacement unit or, less frequently, a centrifugal blower is used. Most positive pressure systems operate within the range of the positive displacement blower or up to 1.05 kg/sq cm (15 psig).

A positive/negative pressure pneumatic conveyor has certain features of the vacuum system and the distribution flexibility of the positive pressure system. A vacuum system can be converted to a combination system by connecting the vacuum pump exhaust pipe to the rotary valve feeder of the receiver-separator. Thus material collected in the separator is discharged into a positive conveying line. The rotary valve acts as an air lock between the negative and positive sides of the system. Material is then distributed to the storage bins through individual feed lines or through a series of two-way diverter valves. A typical positive/negative pneumatic conveyor is shown in Fig. 5-1.

Quicklime and hydrated lime can be stored in hopper-bottom concrete or steel facilities since both are noncorrosive materials. The interior of storage vessels should not be painted to avoid the possibility of product contamination. Storage bins or silos must be airtight to prevent air slaking caused by the moisture content of atmospheric air. In this respect, hydrated lime is more stable than quicklime when stored for extended periods. There are some differences between quicklime and hydrated lime which must be considered in designing the storage facilities. Quicklime lime is generally free-flowing and will discharge readily from storage bins if the hopper bottoms have a minimum slope of 60 degrees from the horizontal. This value is related to the angle of repose of quicklime which, on the average, can vary between 50 to 55 degrees.[2] Nevertheless, it is considered good practice to provide some type of flow-aiding device to regulate material discharge under all conditions. Hydrated lime, on the other hand, has a tendency to arch because of its physical characteristics and much smaller particle size. Therefore, more elaborate mechanical or aeration activators are necessary to insure a continuous discharge of material from storage. Detailed descriptions of the various types of devices commonly used to facilitate free flow of material from storage can be found in references 2 and 4.

Sizing of storage facilities should be based on daily lime demand, type and reliability of delivery, future chemical requirements, and flexibility of expansion. A minimum sufficient storage should be provided to supply a 7-day lime demand, however, sufficient storage to supply lime for 2 to 3 weeks is desirable. In any case, the total storage volume should be at least 50 percent greater than the capacity of the delivery rail car or truck to insure adequate lime supply between shipments.[2] Average bulk density values used in structural design are 640 kg/cu m (40 lb/cu ft) for hydrated lime and 960 kg/cu m (60 lb/cu ft) for quicklime.[3]

LIME FEEDERS

The term feeder, as used in this report, refers to the mechanical devices employed to continuously deliver a measured amount of dry lime to the mixing equipment. Solution feeders are mostly limited to the smallest treatment plants, where bagged hydrated lime is handled and process lime is prepared in batch or intermittent form.

There are two basic types of dry chemical feeders: volumetric and gravimetric. Each type is in turn available in a variety of designs and models, according to the preferences of equipment manufacturers. Regardless of type, all dry feeders share two essential components:

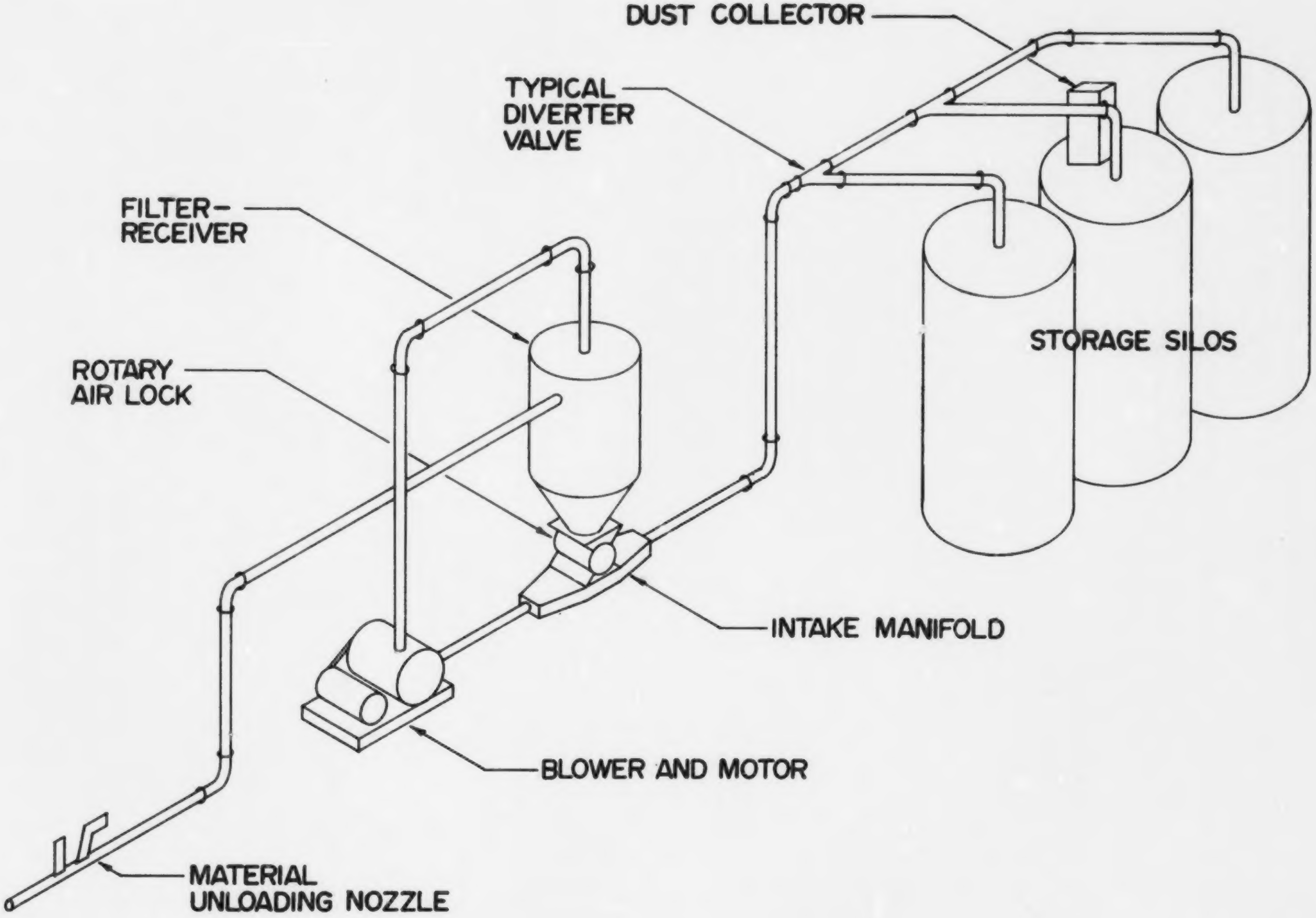
DUST COLLECTOR
TYPICAL DIVERTER VALVE
FILTER-RECEIVER
ROTARY AIR LOCK
STORAGE SILOS
INTAKE MANIFOLD
BLOWER AND MOTOR
MATERIAL UNLOADING NOZZLE

Figure 5-1 Typical positive-negative pneumatic conveying system

1. A day storage hopper, where material is transferred from the lime silos to provide a uniform supply to the feeding element. This hopper has a contracting bottom through which the chemical flows by gravity.

2. An adjustable feeding element to vary the rate of chemical feed. The feed rate is controlled by volume (volumetric feeder) or by weight (gravimetric feeder).

When hydrated lime is used, a solution tank is frequently added to mix lime with water and form a slurry, which is then fed to the process. If quicklime is used, the solution tank is replaced by the slaking equipment.

Day Storage Hoppers

The capacity of the day hopper should be sufficient to store no less than eight hours' supply at the maximum feed rate. In most cases, the hopper bottom slopes at least 60 degrees. This angle would normally assure free flow of quicklime independent of particle size. On the other hand, hydrated lime will tend to arch or bridge, even if the bottom slope is steeper than 60 degrees. Closely related to bridging is the phenomenon of flooding which occurs when an arch of material suddenly collapses and inundates the feeder. Various types of agitating devices are used to prevent arching. Several manufacturers of chemical feeders (Bif, Infilco, Wallace & Tiernan, among others) incorporate paddle type (internal) or pulsating diaphragm type (external) agitators as part of their feeding equipment. When the storage hopper is not included with the feeder, three general classes of agitators are available: electromagnetic or electromechanic vibrators as manufactured, by Eriez, Jeffrey, Syntron and others; aerators (air pads and air diffusers), as manufactured by Airnetics, Bibco, National and others; and the live-bottom bins originally developed by Vibra Screw. Regardless of their operating principle, agitators aim at promoting the flow of bulk materials that tend to pack in storage containers. It is critical to stop agitation when the feeder is not in use, since continuous vibration could actually defeat its purpose by deaerating the material and increasing its density (packing).

The flood prevention device most commonly used is the rotary vane inlet valve which allows only a fixed amount of material to discharge from the storage hopper at any given time. The rotary valve is also utilized as a volumetric feeder.

Volumetric Feeders

Volumetric feeders deliver a constant, preset volume of chemical regardless of changes in material density. The accuracy of the volumetric feeder is closely related to the physical characteristics of the chemical and is greater for uniform, cohesive materials which tend to flow readily. On the other hand, this type of feeder is less reliable when the density of the material handled varies. Variations in density can be compensated by recalibrating the feeder whenever a change occurs. Nevertheless, in the case of hydrate and quicklime, which exhibit wide variations in bulk density, the error of a volumetric feeder is normally in the 5 percent range by volume.

Most volumetric feeders operate on the principle of displacing a predetermined volume of chemical from the point where it leaves the storage hopper to the point of material discharge. The method used to move the material can be a travelling (Wallace & Tiernan) or vibrating (Vibra-Screw) belt; a screw-type feeder (BIF, Vibra-Screw, W&T); an oscillating throat at the base of a hopper (BIF); a roll-type feeder (W&T); a rotary vane or paddle (BIF); or a vibrating feeder (Syntron). Although a few other types of volumetric feeders are still found in treatment plants,[2] the types listed above are the most frequently used. The screw or helical conveyor appears to have gained wide acceptance in lime feeding applications and each of the leading manufacturers offer several modifications of the basic configuration. A screw feeder is a positive displacement device that delivers a constant stream of chemical from the storage hopper. Feeder capacity can be varied by simply adjusting the speed of the screw shaft. Fig. 5-2 illustrates a typical screw type feeder. The capacity range of volumetric feeders varies widely from as low as 6 to 1 for the roll-type, which is driven by a constant speed motor, up to 200 to 1 for a screw feeder which is equipped with variable speed drive. For best results, lime feeders should be selected to operate in the 40 to 1 range. Volumetric feeders are considerably cheaper than the gravimetric type, therefore their application can be justified when only limited funds are available or when greater chemical feeding accuracy is not required.

Gravimetric Feeders

A gravimetric feeder is indicated when chemical dosage must be accurately and reliably measured. In this type of feeder, the quantity of material discharged in a unit of time is continuously weighed and the speed of operation automatically adjusted to maintain a constant weight. Consequently, feeder accuracy is not affected by changes in bulk density and variations in particle size. Despite its higher first cost, a gravimetric lime feeder is often warranted, even for small treatment plants. Apart from eliminating the need for recalibration, savings in chemicals are frequently achieved due to greater feeding accuracy and reliability, i.e., operation and maintenance costs are reduced.

Gravimetric feeders are available in three types: pivoted belt, rigid belt and loss-in-weight hopper. The two belt types include an endless traveling belt conveyor supported on weighting scales, a counter-weight assembly to balance the load on the belt and controls to automatically adjust the rate of feeding. The loss-in-weight type uses the loss of weight in a hopper, rather than the instantaneous weight on a belt conveyor, to adjust the material feed rate. Belt type gravimetric feeders are available from a number of manufacturers including BIF, Jeffrey, Syntron, Vibra-Screw and W&T. Flow of material is normally regulated by throttling an inlet gate located in the passage between storage hopper and belt; by changing the speed of a rotary inlet valve, or by changing the belt speed. Control action can be achieved by mechanical, pneumatic, electric or electronic means. Fig. 5-3 shows a typical gravimetric feeder.

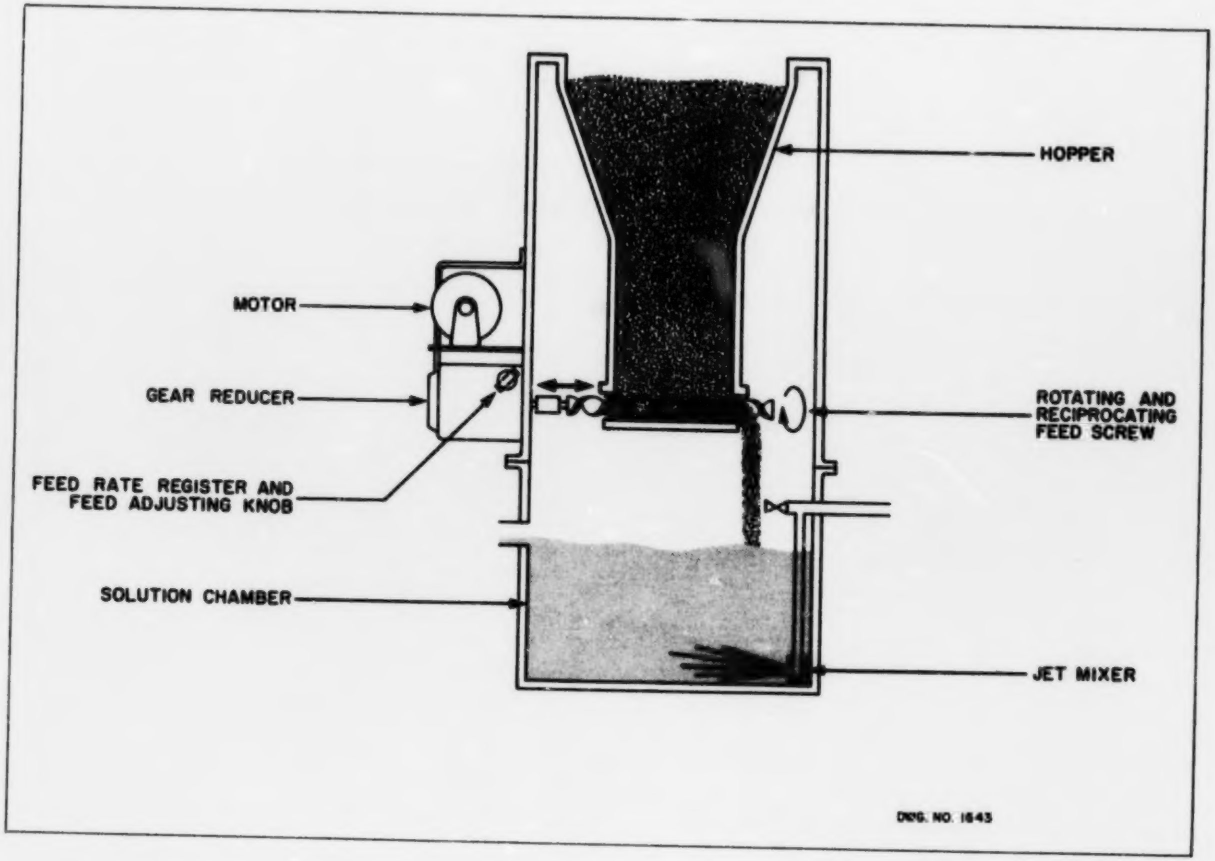
HOPPER
MOTOR
GEAR REDUCER
ROTATING AND RECIPROCATING FEED SCREW
FEED RATE REGISTER AND FEED ADJUSTING KNOB
SOLUTION CHAMBER
JET MIXER
DWG. NO. 1643

Figure 5-2 Typical screw type volumetric feeder (courtesy of Wallace & Tiernan, division of Pennwalt Corporation)

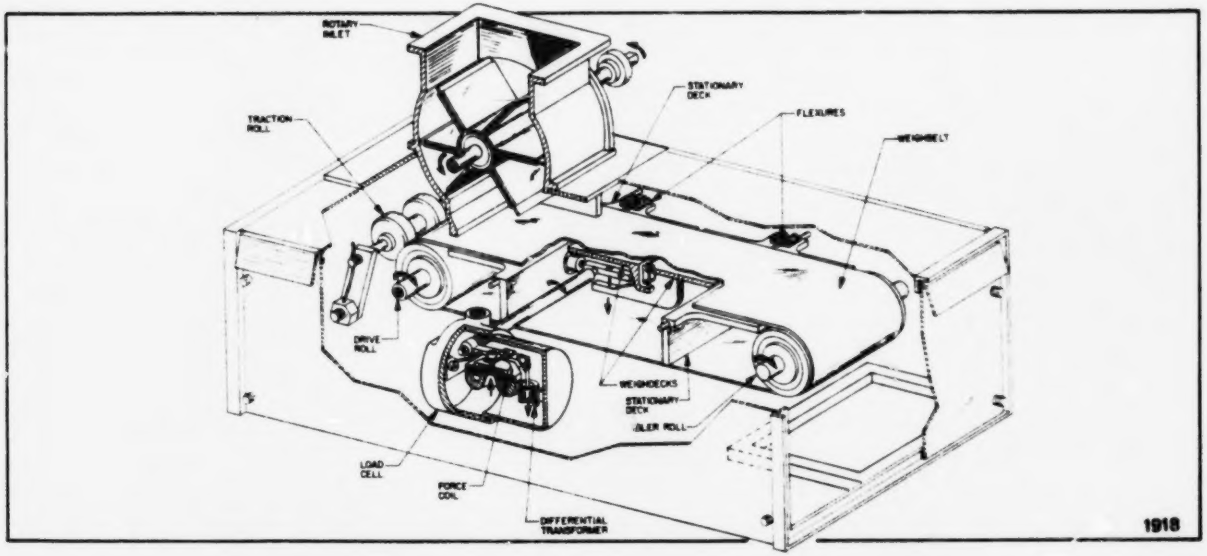
ROTARY INLET
TRACTION ROLL
STATIONARY DECK
FLEXURES
WEIGHBELT
DRIVE ROLL
WEIGHDECKS
STATIONARY DECK
IDLER ROLL
LOAD CELL
FORCE COIL
DIFFERENTIAL TRANSFORMER
1918

Figure 5-3 Typical belt type gravimetric feeder (courtesy of Wallace & Tiernan, division of Pennwalt Corporation)

The standard capacity range of a gravimetric feeder (10-100 to 1) can be greatly increased by combination of control modes or the addition of equipment options. For instance, Wallace & Tiernan inlet gate or rotary valve control (10 to 1 range) can be combined with a variable belt speed control (20 to 1) for a combined range of 200 to 1. This can be further increased by adding a 10 to 1 gear box for a resultant capacity range of 2000 to 1. The loss-in-weight type, developed by BIF, is electronically controlled and has a capacity range of 10 to 1. Most manufacturers of gravimetric feeders will guarantee a minimum accuracy of within + 1.0 percent, by weight, of the set rate. For uniform and free flowing materials, the error can be reduced to ± 0.25 percent.

DISSOLVING OF LIME

As indicated previously, before a measured amount of lime is fed to water or wastewater, it is first mixed with water either in a dissolving tank (hydrated lime) or in a slaker (quicklime). In each case, mixing of lime and water is done for different reasons. Hydrated lime is prewetted to facilitate transport to the point of application and improve dispersion and efficency after it is added to the process. In general quicklime does not react uniformly with water and therefore should never be applied dry. The only exception would be a high calcium, soft burned quicklime of small particle size and uniform grading. (The most common form of commercial lime is the crushed or pebble type,[2] which ranges in effective partial diameter from about 2 to 1/4 inches).

Lime Dissolvers

Both volumetric and gravimetric feeders handling hydrate can be readily fitted with dissolving or solution tanks. Dissolvers are often supplied as part of a packaged feeder-solution system. Dissolvers are usually sized to provide three to five minutes of detention at the maximum rate of feed. Concentration of lime solution is usually kept at or below 6 percent. Mixing and agitation is accomplished by water or compressed air jets at a minimum pressure of 2.8 kg/sq cm (40 psi) or by mechanical agitators. Depending on the solution tank size, one or two impeller type agitators are provided to effect a more rapid and thorough mixing of lime and water. Due to the noncorrosive properties of lime solutions, dissolving tanks are usually made of steel.

Lime Slakers

A lime slaker is used to add water to quicklime and accomplish the slaking reaction. Two basic types of slakers are available: detention type which produces a lime slurry, and pug mill or paste type which produces a viscous, paste-like product. Both types are provided with dilution tanks to lower the concentration of slaked lime to that of a milk-of-lime (thin slurry). They also include grit removal equipment, vapor and dust separators, and thermostatic controls for personnel safety.

The major difference between the two types of slakers rests in the ratio, by weight, in which water and lime are mixed. In detention slakers this ratio averages 3½ to 1 on a weight basis, while in paste slakers, the proportion of water to lime is about 2 to 1. In mixing water and quicklime, two extreme conditions should be avoided. When too much water is added, i.e., water-lime ratios in excess of 6 to 1, the surface of the material hydrates rapidly forming a coating which hinders water penetration to the center of the particle disintegration. This reaction is commonly called "downing" and results in delayed or incomplete slaking and coarser hydrate particles. Downing is more likely to occur when cold slaking water is used. On the other hand, if insufficient water is added, "burning" will occur as a result of excessive reaction temperature (120-260 C). Some slaking water escapes as steam and this loss will leave a considerable portion of particles unhydrated.

Dentention Slakers - The detention type slaker is manufactured in the United States by BIF and Dorr-Oliver at the present time. The BIF unit is divided in two, three, or four compartments, depending on slaker capacity and detention time needed for complete hydration. Quicklime is fed continuously to the first compartment where water is added and the mixture blended by a propeller-type agitator. The lime slurry formed overflows into the second compartment where the slaking process is completed. Mechanical agitation is provided to promote hydration by continuously exposing lime particles to moisture. In case a third and fourth slaking compartment is required, the principle of operation is the same and each additional compartment will be equipped with a separate agitator. From the last slaking compartment the hot slurry overflows into a separation chamber where it is further diluted and agitated by water jets to promote settling of grit particles. In the large capacity models, i.e., above 450 kg/hr (1000 lb/hr), a helical screw, driven by an electric motor, is recommended for continuous removal of grit. Below 1000 lb/hr (450 kg/hr) grit removal is done manually. Finally, the milk-of-lime slurry flows over a weir into the outlet. Fig. 5-4 shows the BIF detention slaker.

Due to the higher water-to-lime ratio, a detention type slaker operates at a much lower temperature than a paste slaker; consequently, the slaking process requires a longer retention time to reach completion (about 20 to 30 minutes as compared to 5 to 10 minutes for paste slakers). To accelerate the hydration reaction, the body of a detention slaker is insulated to reduce heat losses. A coil type heat exchanger is also offered as an option to preheat the slaking water by recovering some of the heat of hydration from the mixing compartment. If hot water is available, it can be blended with slaking water to obtain a desirable process temperature of 77-88 C. It should be pointed out that the ideal slaking temperature is closely related to the reactivity of quicklime. If the material handled is a quick reacting lime ("soft" burned), water at ambient temperature would still produce quick slaking and temperature rise. Conversely, "hard" burned quicklime would normally slake very slowly and the addition of cold water will tend to further delay the reaction.

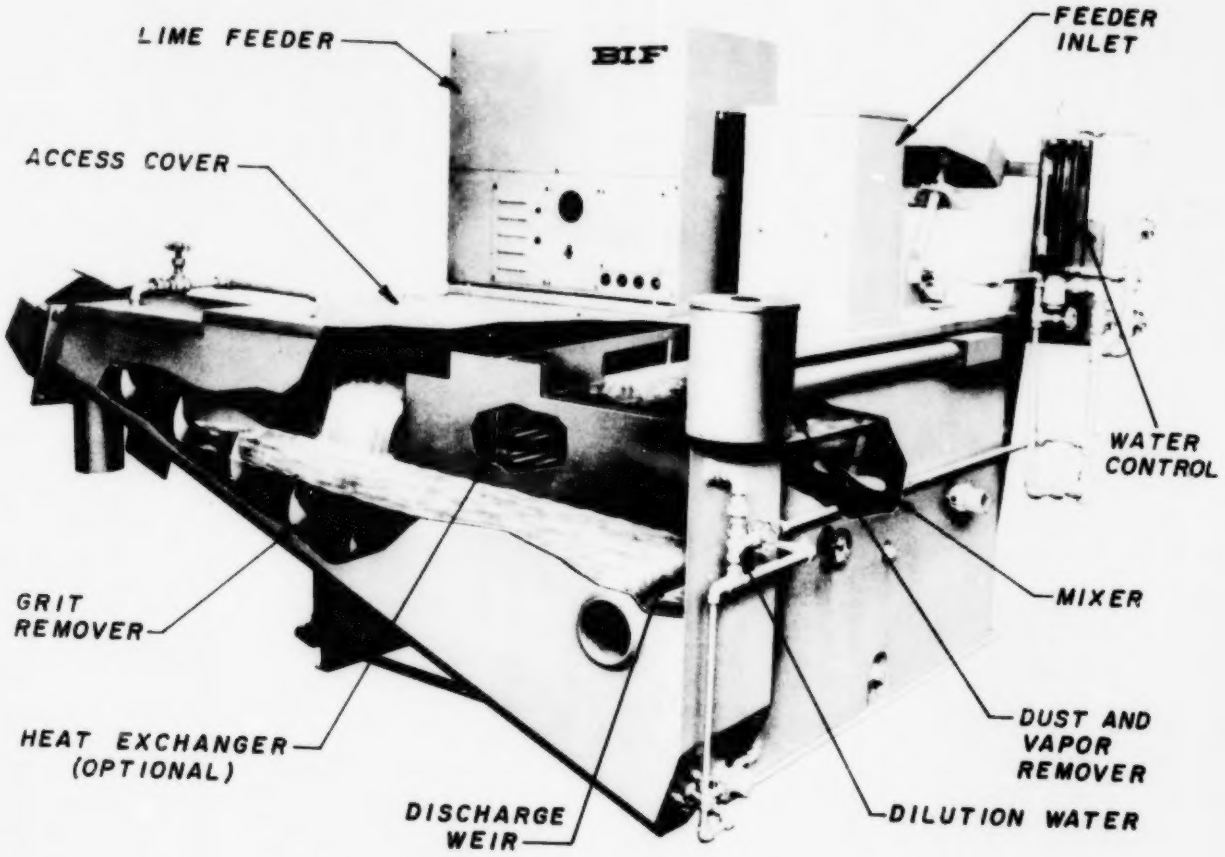
LIME FEEDER
BIF
FEEDER INLET
ACCESS COVER
WATER CONTROL
GRIT REMOVER
MIXER
HEAT EXCHANGER (OPTIONAL)
DUST AND VAPOR REMOVER
DISCHARGE WEIR
DILUTION WATER

Figure 5-4 Typical detention type slaker (courtesy of BIF, a unit of General Signal Co.)

Several methods can be used to control the supply of slaking water. Manual control is the simplest and can be used when the rate of lime feed is fairly constant. As will be seen later however, feeder operation is often controlled by variables such as wastewater flow and pH; then the amount of water of hydration has to be adjusted accordingly to maintain the required water-to-lime ratio.

Paste Slakers - Paste type slakers are manufactured by Wallace & Tiernan and Infilco. The design and operation principle of these units are very similar so the description now given applies to both. The slaker body is divided into two compartments. Quicklime and water are fed continuously to the inlet end of the slaking compartment in a ratio of approximately 2 to 1 (water to quicklime) by weight. The lime-water mixture is thoroughly mixed and moved to the discharge end of this compartment by two sets of counter-rotating (pug mill) paddles. The mixing paddle shafts are driven by a gear reduction unit. The torque exerted on the gear reduction unit controls the hydration water supply through a torque actuated valve. An increase in torque, indicating an increase in viscosity of the paste, opens the water valve and admits additional water to the inlet end of the slaking compartment. High consistency of the paste is maintained to carry grit and inert material through the slaking compartment. When it reaches the end of the first compartment, slaked lime flows over a weir and drops into the grit removal compartment. As it moves over the weir, the heavy paste is broken by water jets and diluted to a lime slurry. Water-to-lime ratio of the slurry varies with changes in slaker input, since the supply of dilution water is normally constant. Once in the second compartment, rakes attached to the same shaft as the mixing paddles agitate the slurry to keep the lime particles in suspension. The slurry then flows under a dust shield and over a weir to the discharge port in the slaker. An external grit conveyor is attached to the discharge compartment. A classifier is provided in the bottom section of the grit conveyor for separation of the grit from the slaked lime. Water is applied in the grit conveyor to continuously wash lime from the grit particles. Fig. 5-5 shows the Wallace & Tiernan paste slaker.

Because of the low water to quicklime ratio, more heat is generated during the slaking reaction in a paste slaker than in a detention type unit. Therefore the former operates at higher temperatures (190-210 F) and shorter detention times. The high operating temperature also eliminates the need to insulate the slaker body. The lower detention time required by the paste slaker results in a more compact design of this unit as compared with a detention type slaker of the same capacity.

IN-PLANT TRANSPORT METHODS

In the small treatment facility using bagged hydrated lime, in-plant handling is commonly limited to taking bags from storage, either manually or with the aid of a hand truck or fork lift, and emptying them into the storage hopper of the chemical feeder. To facilitate bag dumping, day hoppers can be equipped with a filling canopy which includes a bag splitter, a screen and a dust collector. As both the treatment plant size and the chemical requirements increase, the methods of transporting lime become more elaborate. In-plant transport systems can be divided into two general groups: mechanical and pneumatic.

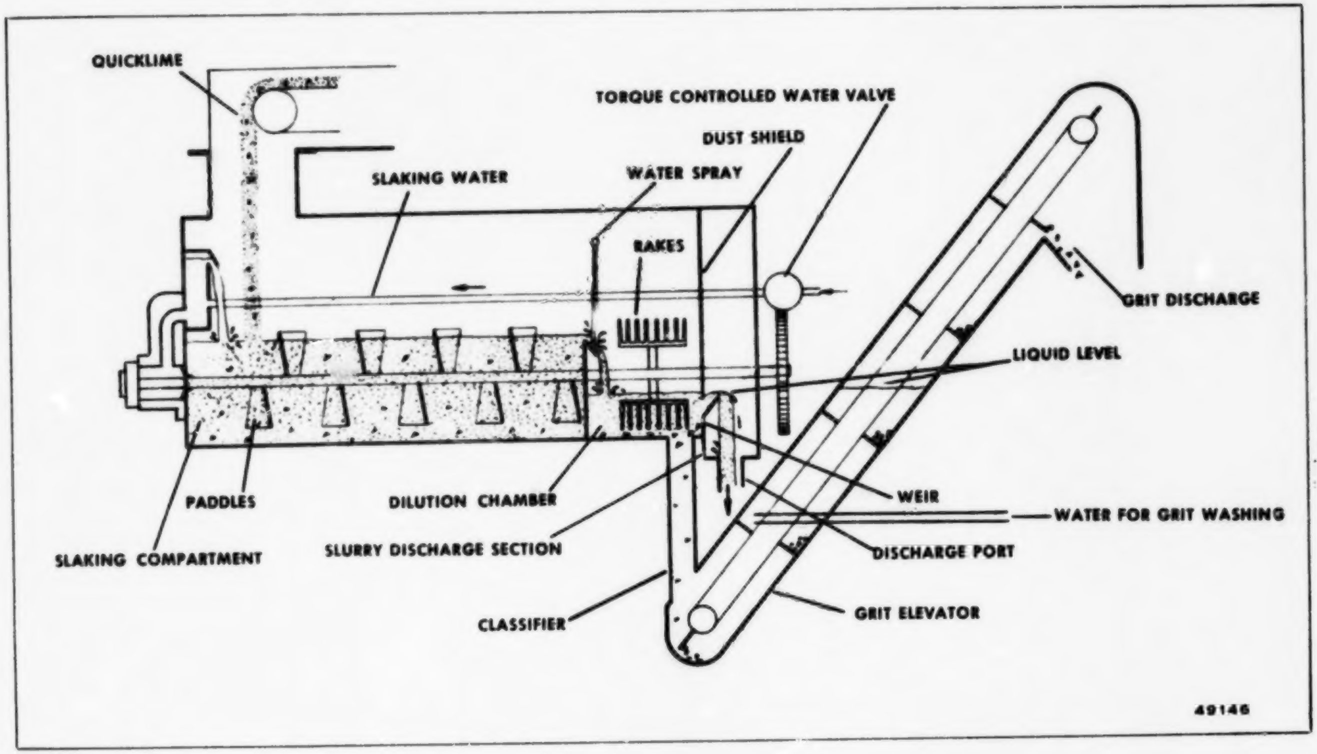
QUICKLIME
TORQUE CONTROLLED WATER VALVE
DUST SHIELD
SLAKING WATER
WATER SPRAY
RAKES
GRIT DISCHARGE
LIQUID LEVEL
PADDLES
DILUTION CHAMBER
WEIR
WATER FOR GRIT WASHING
SLAKING COMPARTMENT
SLURRY DISCHARGE SECTION
DISCHARGE PORT
CLASSIFIER
GRIT ELEVATOR
49146

Figure 5-5 Typical paste type slaker

(courtesy of Wallace & Tiernan, division of Pennwalt Corporation)

As was mentioned before, mechanical conveyors require less power to operate per ton of solids handled than pneumatic conveyors, and therefore the type of transport system to use is a matter of careful evaluation. It is common to combine pneumatic and mechanical units and retain the best features of each method to achieve flexibility, reliability and economy of operation.

Mechanical Transport

In-plant mechanical transport systems include a variety of conveying devices used to move material from one point to another which is at either the same or a different elevation. Mechanical conveyors and elevators were briefly discussed under lime unloading methods. They find further application where chemicals have to be transferred from storage to the point of usage. Where lime recalcination is practiced, mechanical conveyors can be used to return the reclaimed product to storage and also to transport the inert ash to a loading area prior to final disposal. Of the various types of conveying and elevating equipment found in industrial plants, only a few have been used in water and wastewater treatment plants. Belt and screw conveyors, bucket elevators, Screw-Lifts, and combination conveyor-elevator (Bulk-Flo) are the types most commonly seen in municipal applications.

Belt conveyors are the most versatile and widely used type of mechanical conveyor. They can transport dry materials over paths beyond the capability of any other conveying device. However, belt conveyors are not recommended for the transport of lime, particularly hydrate or reclaimed lime, because of dusting.[2] The dust problem can be solved by adding covers over the conveyor and an exhaust air system to collect the dust. This configuration however, eliminates some of the basic advantages of the belt conveyor concept and there are simpler ways to approach a dusting situation.

Screw conveyors are one of the oldest and simplest methods of handling granular materials which exhibit noncorrosive and low abrasion characteristics. The basic screw conveyor is compact and can be mounted in horizontal and inclined positions. This versatility is particularly advantageous in congested locations, when the distance does not exceed about 60 meters (200 feet), and the slopes are not greater than about 35 degrees. Preliminary sizing information for screw conveyors has been given in Table 5-1.

Bucket elevators are widely used to elevate bulk materials. Bucket elevators are available in two types: chain-mounted and belt-mounted, and the latter is used when handling abrasive materials. Data for preliminary sizing of bucket elevators has also been given in Table 5-1.

The Screw-Lift is a vertical screw conveyor installed in a dust proof enclosure. The unit is compact and it is used to elevate both granular and pulverized materials. The Screw-Lift is normally fed by a horizontal screw conveyor, and therefore it could also be considered as a combination conveyor-elevator.

Bulk-Flo is an enclosed elevator and conveyor which can carry bulk materials in horizontal, vertical or inclined positions. This flexibility can then be used to replace several straight line conveyors with a single unit.

Mechanical material handling is a specialized field and the final design of a mechanical system for in-plant conveying of lime should be done in consultation with the equipment manufacturers. Rexnord (previously Rex Chainbelt) and Link-Belt are two companies in the wastewater treatment field with extensive experience in materials handling.

Pneumatic Transport

The basic types of pneumatic transport systems were described earlier under the section entitled Transport Methods. Pneumatic conveying can also be used for in-plant lime transport. This approach becomes more advantageous as the size of the plant increases and chemical processes become more sophisticated. Pneumatic conveying is probably the only streamlined means of moving chemicals in a large treatment facility where the process areas are interconnected through piping tunnels. As an example, in the CCCSD water reclamation plant,[1] quicklime and recalcined lime will be handled in pneumatic conveying systems. These systems include quicklime unloading; transfer of a mixture of quicklime and recalcined lime over a distance of about 120 meters or 400 feet from the storage silos to the slakers day hopper; and return of reclaimed lime to storage (a distance of about 300 meters or 1,000 feet). Also, inert ash is transported pneumatically from the sludge burning furnaces to holding hoppers from where it is loaded into trucks for final disposal.

Pneumatic conveying is still much as an art as it is a science. Design depends largely on practical knowledge, and the judgment and experience of the equipment manufacturers plays a key role. A number of companies specialize in the pneumatic field (Butler, Fuller, Semco, Sprout-Waldron). The more progressive manufacturers would normally size a conveying system only after the particular material has been tested in a pilot plant. Close cooperation between the purchaser and the manufacturer is required to arrive at a sound design. A satisfactory approach could be for the purchaser to prepare a comprehensive performance specification, preceded by a careful assessment of the knowledge and experience of the equipment manufacturers.

SAFETY CONSIDERATIONS

Although lime is considered a nonhazardous chemical, certain precautions should be observed regarding the caustic nature of the material. A comprehensive review of safety practices can be found in reference 2 of this section.

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3. Lime for Water and Wastewater Treatment. BIF. Providence, R.I., Ref. No. 1.21-24. June, 1969. 19 p.

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SECTION VI

LIQUID PROCESSING WITH LIME

GENERAL CONSIDERATIONS

Lime can be added to wastewater either ahead of primary treatment or following biological treatment. In the latter case, lime addition is mostly practiced to remove phosphorus, i.e., as part of a typical tertiary treatment sequence.[1]

On the other hand, when the use of lime in the primary treatment stage is coupled with biological treatment, much of the organic carbon load is removed from subsequent treatment processes. This reduction in the organic carbon load reduces the needed size of subsequent biological units and allows stable oxidation of ammonia to nitrate (nitrification).[2] Besides the removal of organic matter, lime improves the removal of phosphorus, heavy metals, grease and viruses. Although the use of lime for phosphorus removal is less efficient with raw wastewaters than it is in tertiary treatment, the residual phosphorus concentration in the primary effluent is sufficiently low for effective biological uptake in the activated sludge process.[3,4]

The improved BOD and suspended solids removal associated with chemical addition greatly increases the mass of raw sludge settled in the primary tanks. When excess sludge from biological treatment is returned to the primaries, the resulting physical-chemical-biological precipitation contains all of the sludge produced in the liquid treatment phase. Precipitation of all sludges in a single basin can simplify subsequent handling of solids. It has generally been found that primary sludges more readily dewater than secondary sludges.[5] Methods for computing sludge quantities are presented in Section X.

PROCESS CHEMISTRY

Many chemical reactions occur when lime is added to raw wastewater. When lime alone is added, the reactions producing most of the sludge involve calcium, magnesium and phosphorus. Other chemical reactions take place coincidentally, such as changes in alkalinity, and precipitation or adsorption of heavy metals. However, calcium, magnesium and phosphorus precipitation are responsible for the bulk of the inorganic chemical sludge production. At the same time, chemical coagulation of the raw sewage solids takes place, resulting in the coprecipitation of the organic sludge. The chemistry of the process is extraordinarily complex, so only a process-oriented review is presented.

Calcium Carbonate Precipitation

At moderate to high lime doses, the bulk of the calcium added to the process is precipitated as calcium carbonate according to the reaction:

$$Ca(OH)_2 + Ca(HCO_3)_2 \longrightarrow 2CaCO_3 + 2H_2O \qquad (6\text{-}1)$$

Water chemistry equilibria would suggest much lower levels of soluble calcium than do actually occur in chemical primary effluents where lime addition is practiced. In other words, the reaction indicated in equation 6-1 usually does not closely approach equilibrium conditions as might be defined by water chemistry transposed from water softening theory. Considering the host of constituents in raw wastewater not present in raw municipal water supplies, it is not surprising to find that there may be competitive reactions that inhibit calcium carbonate precipitation.

Schmidt and McKinney,[3] in fact, demonstrated with jar tests that polyphosphate could completely inhibit calcium carbonate precipitation up to a pH of 9.5 Orthophosphate also caused inhibition of the reactions, as shown in Figure 6-1. The theory cited for this inhibition is that phosphorus is adsorbed on the growing faces of the calcium carbonate crystal, preventing further calcium carbonate growth. Schmid and McKinney concluded that lime recovery is not justified for low pH operations, since there is very little, if any, calcium carbonate precipitation below a pH of 9.5.

Control of nucleation of the calcium carbonate crystal and crystalline growth are important factors governing the extent of completion of the reaction indicated in equation 6-1. Allowing the reaction to take place in the presence of calcium carbonate crystals enhances both the reaction rate and the extent of its completion. In terms of the treatment process, crystals can be recycled from the sedimentation tank underflow to encourage calcium carbonate precipitation. This principle has long been recognized in water treatment practice and has led to the development of solids contact-type clarifiers. For instance, Hartung[7] found that in a water softening operation soluble calcium decreased when the solids concentration in the reaction chamber was increased from one and a half to two percent total solids by weight. Stone[8] found in both laboratory and full-scale water softening tests that the soluble calcium level was decreased by solids recycle. It was concluded that the lime dose could be reduced for the same effluent hardness with solids recycle; or alternatively, at the same lime dose, effluent hardness could be reduced by solids recycle.

In a raw wastewater application, Horstkotte, et al.[9] found that with no solids recycle, the hardness increase across the primary sedimentation tank was 32 mg/l at pH 11.0 operation. With solids recycle and the maintaining of flocculator solids in the 900 to 1500 mg/l level, the hardness increase across the primary was only 6 mg/l. Most of the change occurred in the calcium ion concentration.

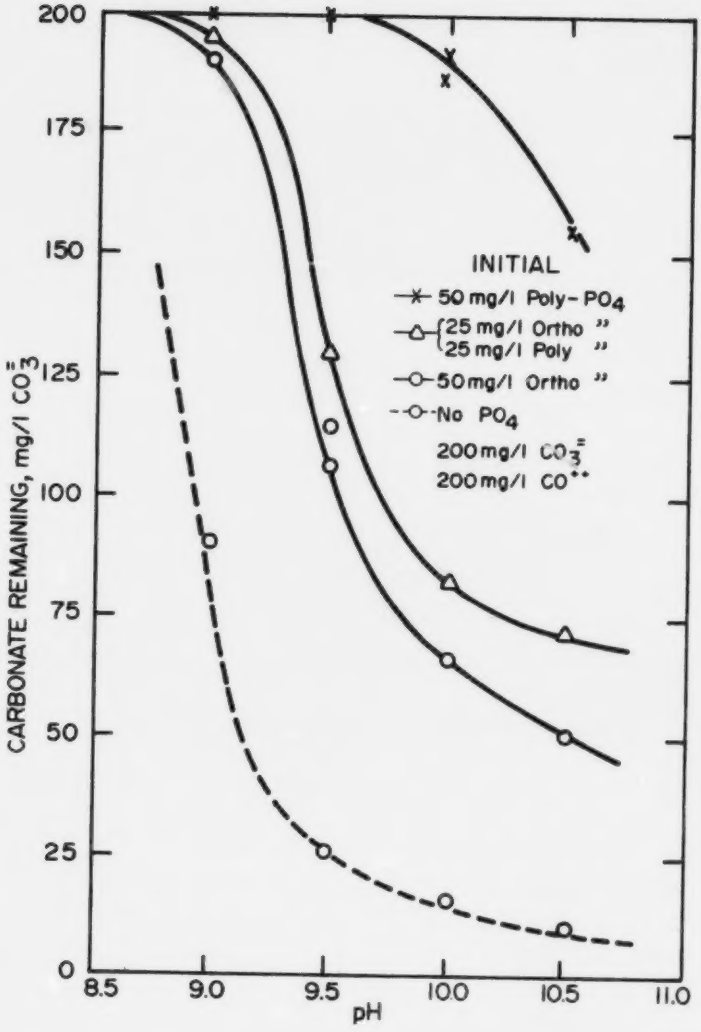


Figure 6-1 Effect of phosphate form on calcium carbonate precipitation

Pressley[10] studied the effect of sludge recycle on coagulation in jar test experiments of raw wastewater. At a pH of 11.65, the rate of removal of soluble calcium was calculated as a function of time. Fig. 6-2 shows the effect of solids content on the rate of calcium removal. As can be seen, little is gained in terms of improving the calcium carbonate reaction rate by increasing the solids level above 2500 mg/l.

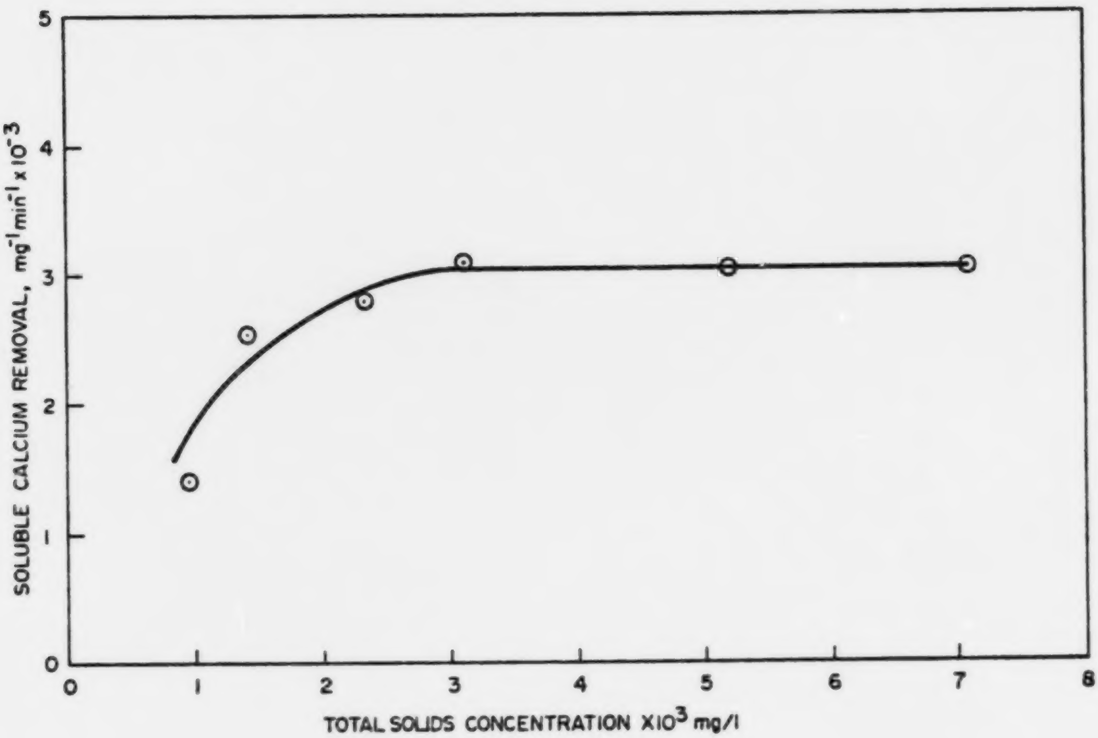


Figure 6-2 Effect of solids concentration on calcium removal

The importance of solids recycle is not limited to hardness considerations. If the calcium carbonate reaction is not complete, the effluent from the clarifier will remain unstable with respect to calcium carbonate precipitation, unless pH adjustment is made. The result of this instability is that the calcium carbonate will plate out on the clarifier itself and downstream structures. For instance, at the South Tahoe Plant, where a tertiary lime application is made and only minimal solids recycle is practiced, copious quantities of solids are deposited on the weirs, piping, and distribution trays above the ammonia stripping tower. Similar scaling has been observed in clarifier weirs prior to pH adjustment at the CCCSD's ATTF. In comparison, far less scale formation has been reported at Envirotech's Salt Lake City pilot plant where solids contact units have been employed. In the latter case, between 0.2 to 1.2 percent TS has been employed in the reaction zone,[12] a level which is much greater than the cited solids recycle applications.

The stability of the effluent is exceptionally important in those treatment systems employing ammonia stripping for nitrogen removal, as calcium carbonate scaling on the tower media has been one of the major operating difficulties of the ammonia stripping process. It should be recognized that ammonia is stripped at high pH. Even effluents which have been stabilized to calcium carbonate at pH 11 will contain free $Ca(OH)_2$ which can react with CO_2 from the air producing scale.

Calcium Phosphate Precipitation

Precipitation of calcium phosphate creates another lime coagulant demand and leads to further sludge precipitation. The exact nature of the precipitate is the subject of continuing controversy. Up until recently, the nearly universal opinion has been that the form of calcium phosphate precipitated was crystalline hydroxyapatite, which has the formula $Ca_5OH(PO_4)_3$. Recently, Menar and Jenkins[6] evaluated calcium phosphate and calcium carbonate precipitation phenomena in both "chemically defined" water systems and in actual wastewater coagulation. Crystalline hydroxyapatite could not be detected either by x-ray diffraction techniques or by solubility tests. Rather, the solubility data suggested the formation of an amorphous tricalcium phosphate, $Ca_3(PO_4)_2$. Further, in the chemically defined systems, where raw sewage organics were absent, Menar and Jenkins found that a phase change eventually took place, whereby crystalline tricalcium phosphate ($Ca_3(PO_4)_2 \cdot 4H_2O$) was formed. The extent of completion of the reaction was not evaluated, nor could the presence of the crystalline phase be detected in the wastewater systems tested.

In explaining the absence of hydroxyapatite Menar and Jenkins[6] make the following statement:

> "Magnesium appears to inhibit the nucleation of calcium phosphate, to slow down the formation of apatite from amorphous calcium phosphate, and to stabilize the formation of tricalcium phosphate."

For the purposes of this report, the simplifying assumption is made that all phosphate precipated is present in the form of amorphous tricalcium phosphate according to the reaction:

$$3Ca(OH)_2 + 2PO_4^{\equiv} \longrightarrow Ca_3(PO_4)_2 + 6\,OH^- \qquad (6-2)$$

Obviously, this is not the only phosphorus removal mechanism operative, since there are other forms of phosphorus than orthophosphate present in raw sewage. As with calcium carbonate solids recycle, the presence of preformed calcium phosphate solids has a catalytic effect on the formation of the calcium phosphate solid phase. Albertson and Sherwood[4] showed with jar tests run on wastewater that solids recycle significantly reduces residual phosphate concentration at constant pH up to a pH of 11. Further, in one case, the effect of solids recycle was to reduce by 50 percent the dose required to achieve the same residual soluble phosphate. Menar and Jenkins[6] showed that the activity product or solubility of tricalcium phosphate decreased with increased solids levels in "chemically defined" systems in experiments conducted up to a pH of 8.

Contrary to the results of previous investigators, Pressley[10] found that soluble phosphate residuals increased with the level of solids recycle in jar tests and that the "organic phosphorus" fraction in the recycle solids accounted for the increase in the systems studied. No increase in orthophosphorus residuals was observed.

Magnesium Hydroxide Precipitation

For most wastewaters, magnesium is not precipitated until enough lime is added to raise the pH above 10.0. The chemical reaction involved is:

$$Mg^{++} + Ca(OH)_2 \longrightarrow Mg(OH)_2 + Ca^{++} \tag{6-3}$$

Soluble magnesium levels are a function of pH and typical values follow:

pH	Soluble Mg as $CaCO_3$, mg/l
10.0	370
10.2	145
10.4	57
10.6	22
10.8	9
11.0	4

In raw sewage applications, the magnesium hydroxide reaction does not closely approach the equilibrium predicted on the basis of $Mg(OH)_2$ solubility. For instance, at the CCCSD's ATTF, the effluent magnesium averaged 33 mg/l at pH 11.0, when a supplemental coagulant dose of 14 mg/l of ferric chloride was added. Apparently the magnesium hydroxide reaction is inhibited, although the specific inhibition mechanism is as yet undefined.

Trace Metals Precipitation

Of the unit processes available for waste treatment today, lime precipitation is one of the most effective methods for removing heavy metals and, as a rule, is more effective than either iron or aluminum.[13,14,15] Trace metals are of significance in water pollution control because many are toxic to the biota in the receiving waters, either at their discharge concentration or through concentration in living cell tissue. Other metals are micronutrients essential for biological growth.

Lime removes trace metals from wastewater through adsorption, flocculation, or by conversion of soluble metals to an insoluble precipitate. Most metals form insoluble hydroxides, oxides, carbonates, sulfates, or chlorides.[14] Solubility data were summarized by Argaman and Weddle[14] and are presented in Table 6-1 for the common trace metals and their precipitates. As can be seen, silver, cadmium, cobalt, copper, iron, mercury, manganese, nickel, lead and zinc ought to form relatively insoluble hydroxides or oxide precipitates when lime treatment is practiced. Actual performance often does not match predicted chemical equilibrium because of slow rates of reaction or the formation of

Table 6-1. SOLUBILITY PRODUCTS OF HEAVY METAL SALTS

Metal	Oxide or Hydroxide		Carbonate		Sulfate		Chloride		Sulfide		Chromate		Arsenate	
Ag, Silver	Ag_2O	$1.9x10^{-8}$	-	-	-	-	AgCl	$2.8x10^{-10}$	Ag_2S	$1.0x10^{-51}$	Ag_2CrO_4	$7.1x10^{-13}$	-	-
Ba, Barium	-	-	$BaCO_3$	$1.6x10^{-9}$	$BaSO_4$	$1.1x10^{-10}$	-	-	-	-	$BaCrO_4$	$2.1x10^{-10}$	-	-
Cd, Cadmium	$Cd(OH)_2$	$2.0x10^{-14}$	-	-	-	-	-	-	CdS	$1.4x10^{-28}$	-	-	-	-
Co, Cobalt	$Co(OH)_2$	$1.6x10^{-15}$	-	-	-	-	-	-	-	-	-	-	-	-
Cu, Copper	$Cu(OH)_2$	$1.6x10^{-19}$	-	-	-	-	-	-	CuS	$4.0x10^{-38}$	$CuCrO_4$	$3.6x10^{-6}$	-	-
Fe, Iron	$Fe(OH)_3$	$2.0x10^{-39}$	-	-	-	-	-	-	FeS	-	-	-	-	-
Hg, Mercury	HgO	$4.0x10^{-26}$	-	-	-	-	-	-	HgS	$3.0x10^{-53}$	$HgCrO_4$	$2.0x10^{-9}$	-	-
Mn, Manganese	$Mn(OH)_2$	$1.6x10^{-13}$	-	-	-	-	-	-	MnS	$7.0x10^{-16}$	-	-	-	-
Ni, Nickel	$Ni(OH)_2$	$2.0x10^{-15}$	-	-	-	-	-	-	-	-	-	-	$Ni(AsO_4)_2$	$3.1x10^{-26}$
Pb, Lead	$Pb_2O(OH)_2$	$1.3x10^{-15}$	$PbCO_3$	$1.5x10^{-13}$	$PbSO_4$	$1.3x10^{-8}$	-	-	PbS	$7.0x10^{-}$	$PbCrO_4$	$3.0x10^{-13}$	$PbHAsO_4$	$4.0x10^{-36}$
Zn, Zinc	$Zn(OH)_2$	$1.6x10^{-16}$	$ZnCO_3$	$2.0x10^{-10}$	-	-	-	-	ZmS	$4.5x10^{-24}$	-	-	$Zn(AsO_4)_2$	$1.3x10^{-38}$

complexes (chelation). In other instances, removals may exceed predicted levels through adsorption or coprecipitation on other compounds.

Two metals, barium and chromium, may pose problems in lime precipitation systems. Barium does not form a hydroxide precipitate, and it is often not removed efficiently with lime. In fact, Maruyama, et al. found, in pilot testing, that ferric sulfate removes barium more efficiently than lime, since barium forms an insoluble precipitate as a sulfate.[15] Chromium in the hexavalent form exists as an oxide (chromate or dischromate anion), which forms a soluble salt with most cations found in wastewater.[14] If reduced to the trivalent form, the metal may precipitate as an insoluble hydroxide (solubility product of 1.0×10^{-30}).

Coagulation

Unlike the situation in water treatment, lime is not added to raw wastewater for the exclusive purpose of precipitating calcium or magnesium. Rather, lime is ordinarily used for precipitation of phosphorus or metals, and for coagulation of raw sewage solids. Only when water reclamation is to be practiced do hardness considerations influence process operation.[9] Criteria for coagulation of raw sewage solids and precipitation of phosphorus compounds may set quite different operating criteria than that for treatment of water hardness alone.

When pH is controlled at 10 or below and lime is the only coagulant, effluents tend to be very turbid and have high concentrations of finely divided or dispersed solids. In other words, the effluents do not appear to be well coagulated. This solids loss results in lower phosphorus removal, since some precipitated phosphorus is lost over the effluent weirs. For cases where a very high degree of phosphorus removal is required in primary treatment, the encouragement of magnesium precipitation is often recommended. The reason is that magnesium hydroxide forms a gelatinous matrix that binds the precipitated calcium phosphate and calcium carbonate together into readily settleable flocs. This normally requires a pH of 10.5 or greater, depending on the raw water magnesium content.

Menar and Jenkins[6] have suggested that additional coagulants be employed for high phosphorus removal below pH 10. Since above pH 8 to 9.6, calcite (calcium carbonate) carries a net negative charge, a cationic material was suggested for coagulation. While they showed that a high calcium ion concentration could fill this role, they suggested that cationic polymers or alum or ferric salts could be more efficient coagulants.

Jar tests conducted at the ATTF have demonstrated that the addition of ferric chloride and its precipitation as ferric hydroxide could be substituted for the high pH conditions conducive to magnesium hydroxide precipitation, while obtaining similar supernatant turbidity and phosphorus levels. The jar test were conducted on CCCSD raw sewage utilizing both lime and iron at the doses and pH levels indicated in Figure 6-3. As can be seen in Figure 6-3, the turbidity at a pH of 9.6 is equal to that obtained at a pH of 11.4. The high clarity obtained at a pH of 9.6 was due to the use of 25 mg/l of $FeCl_3$ as a supplemental coagulant. To obtain effluent phosphorus levels less than 1 mg/l

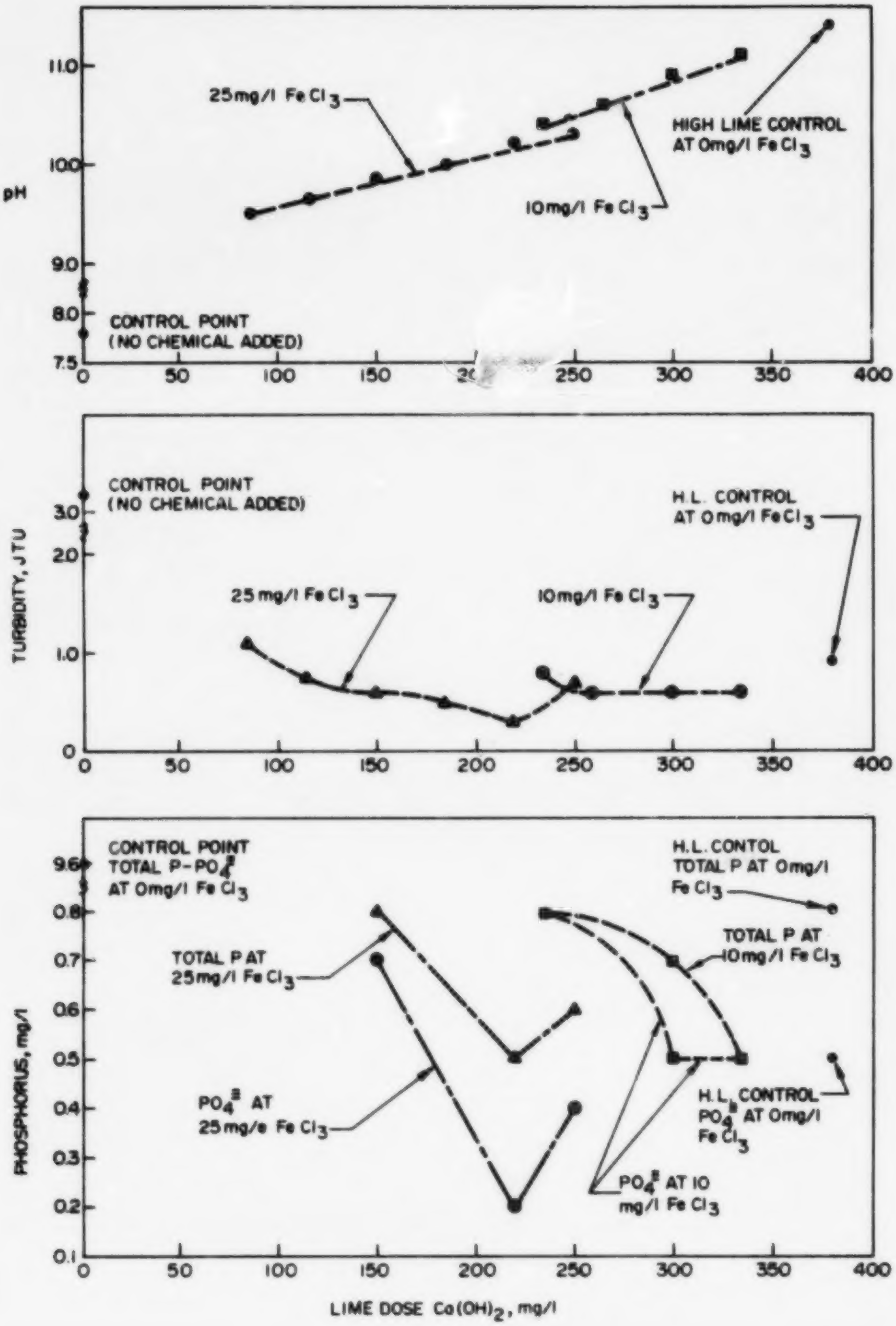


Figure 6-3 Lime and iron dose vs. supernatant quality for CCCSD wastewater

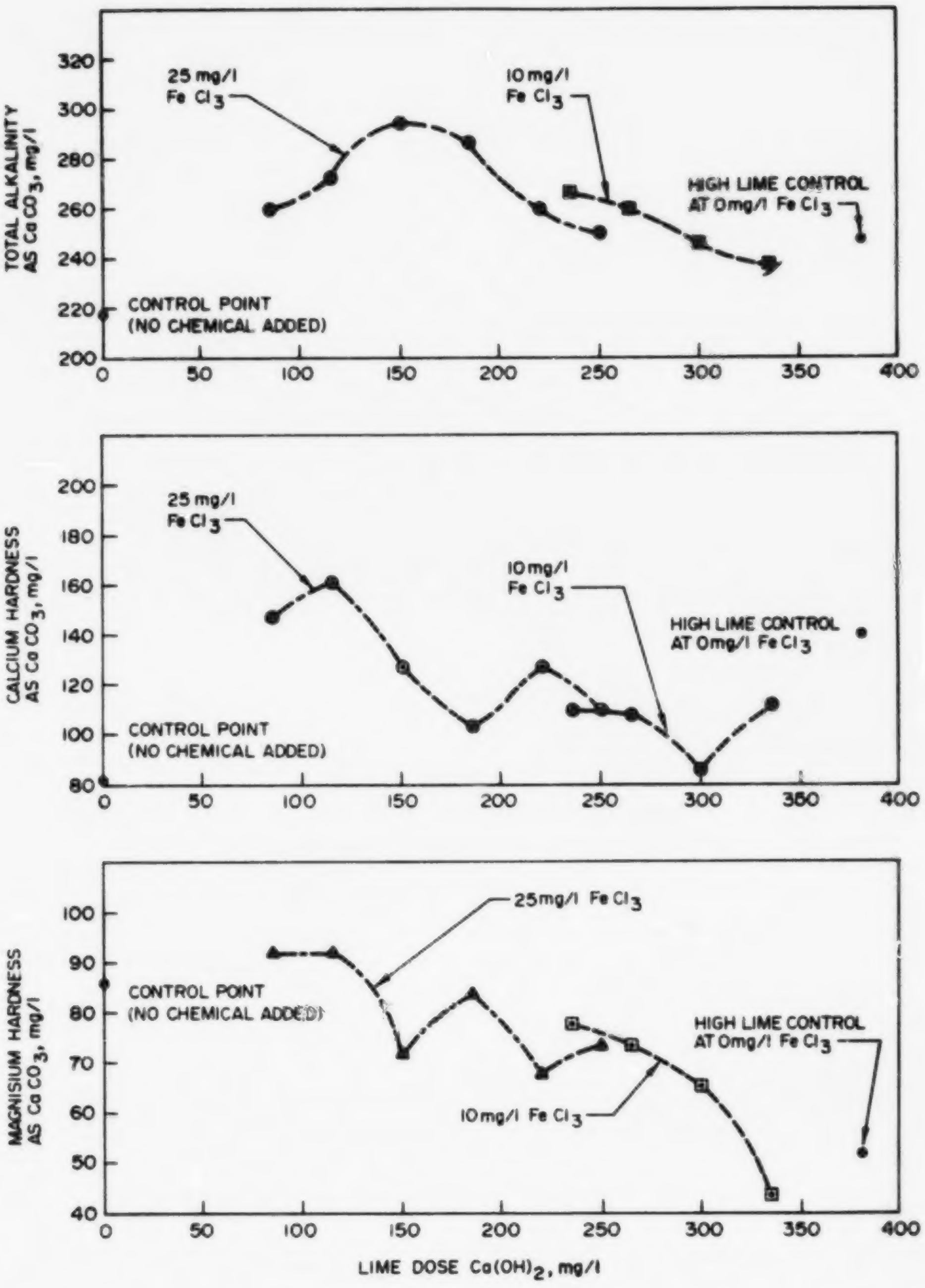


Figure 6-3 (continued) Lime and iron dose vs. supernatant quality for CCCSD wastewater

P, however, the pH had to be raised to at least 9.85 (lime dose = 150 mg/l). Lower pH levels resulted in higher supernatant phosphorus as shown in Figure 6-4 for another jar test series. Nonetheless, Figure 6-4 demonstrates that there is a broad pH range where comparable phosphorus removals are obtainable as long as appropriate iron doses are employed.

Other items of interest in Figure 6-3 are the alkalinity and hardness data. Note that there is no clear minimum solubility point for calcium, rather there is a broad range where the calcium concentration is roughly in the same range (pH 10.3 to 11.0). This is contrary to what would be predicted from water softening experience which usually indicates a minimum solubility point for calcium in the pH 9.5 to 10 range. Note also that magnesium is not completely removed at pH 11.4, contrary to solubility predictions. Very little magnesium is precipitated up to a lime dose of 250 mg/l (pH = 10.1), yet excellent clarity is obtained. This, again, is evidence that iron has substituted for magnesium as the coagulation aid.

Quite similar hardness relationships were reported by Burns and Shell[12] for Salt Lake City wastewater when lime was used without supplemental coagulants. Effluent calcium was lowest in a pH range from 10 to 11, with a minimum at pH of 10.4. Complete magnesium removal did not occur even at a pH of 11.5 (Figure 6-5).

These hardness relationships led to the decision to select an operating pH of 11.0 at the ATTF. This was the point of minimum total hardness, which is a consideration when the treatment product is to be reused. The data in Figure 6-3 on CCCSD wastewater can be reworked to show another interesting relationship. Knowing the lime requirement for phosphorus removal (Equation 6-2), and the measured supernatant calcium, the loss of calcium to tricalcium phosphate formation and to soluble calcium in the supernatant can be calculated. Theoretically, this loss when subtracted from the lime dose, gives the lime precipitated as calcium carbonate. Obviously, if all the calcium added is lost to the supernatant and phosphorus precipitation, there can be no lime recovery as no calcium carbonate is precipitated. In Figure 6-6, the calcium loss is expressed as a percent of the lime dose (as $CaCO_3$) and plotted against the lime dose (as $Ca(OH)_2$). It can be seen that at pH 9.5 nearly all the calcium is lost. Other investigators have also found that at pH 9.5 or less, there is essentially no calcium carbonate formation.[3,6,12] It can also be seen from Figure 6-6, that the pH must be at least 10 for the loss to be less than 30 percent, leaving 70 percent for lime recovery. In practice, losses occur in other parts of the treatment system, and obtainable recovery is even less.

Subsequent work done in connection with the design of a wastewater treatment plant in Australia showed that either ferrous or ferric sulfate could be substituted for ferric chloride. Also, an investigation at the ATTF showed that alum or aluminate could be substituted for ferric chloride as the supplemental coagulant.

The choice of coagulants to be employed should be based on jar tests for screening purposes, and if possible, final selection should be based on pilot

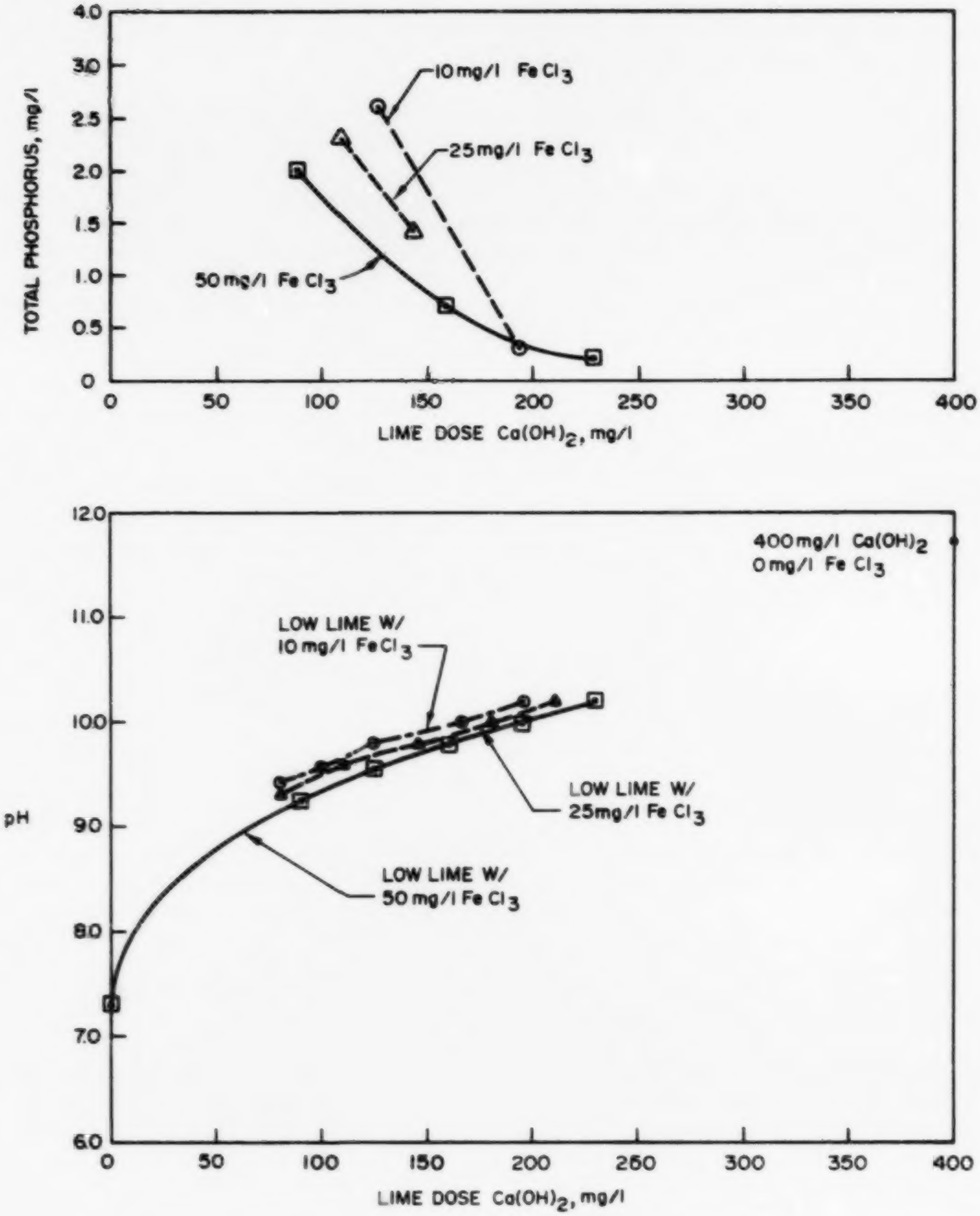


Figure 6-4 Phosphorus removal for low pH operation.
Lime and iron treatment of CCCSD wastewater

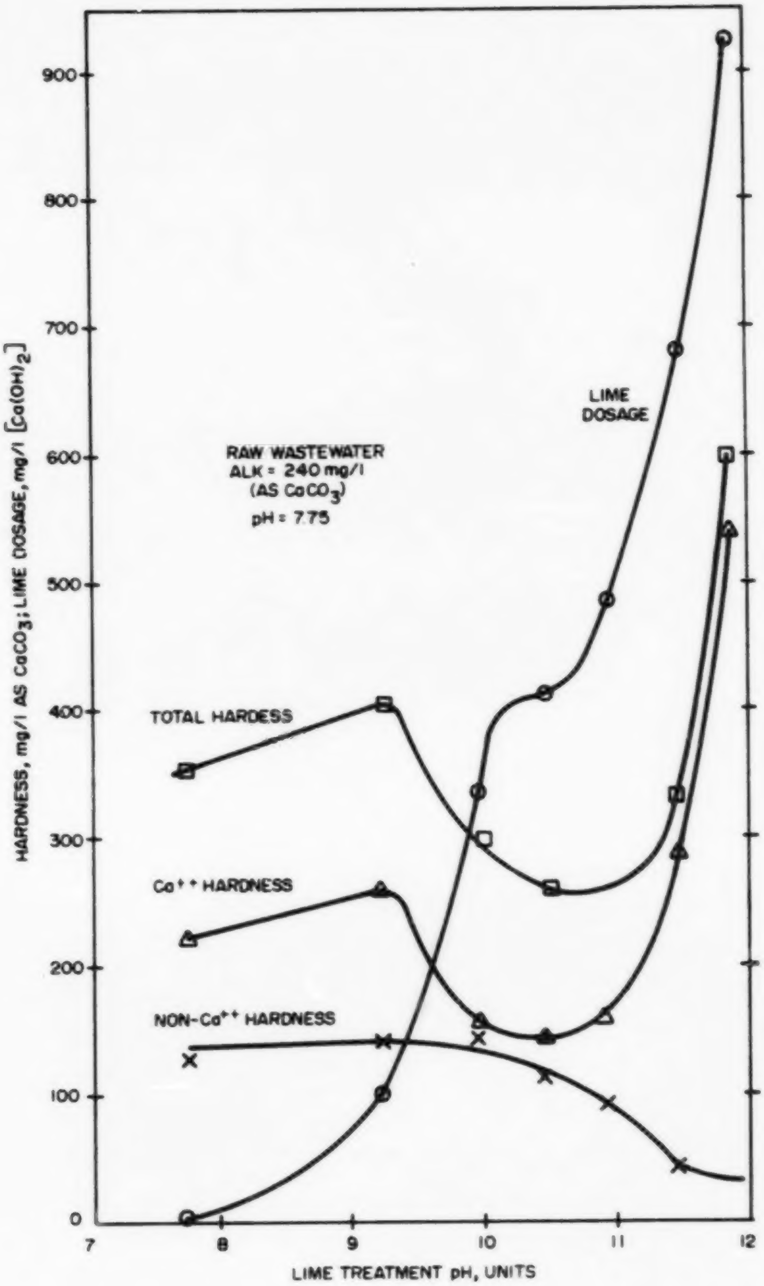


Figure 6-5 Effect of lime treatment on Salt Lake City wastewater

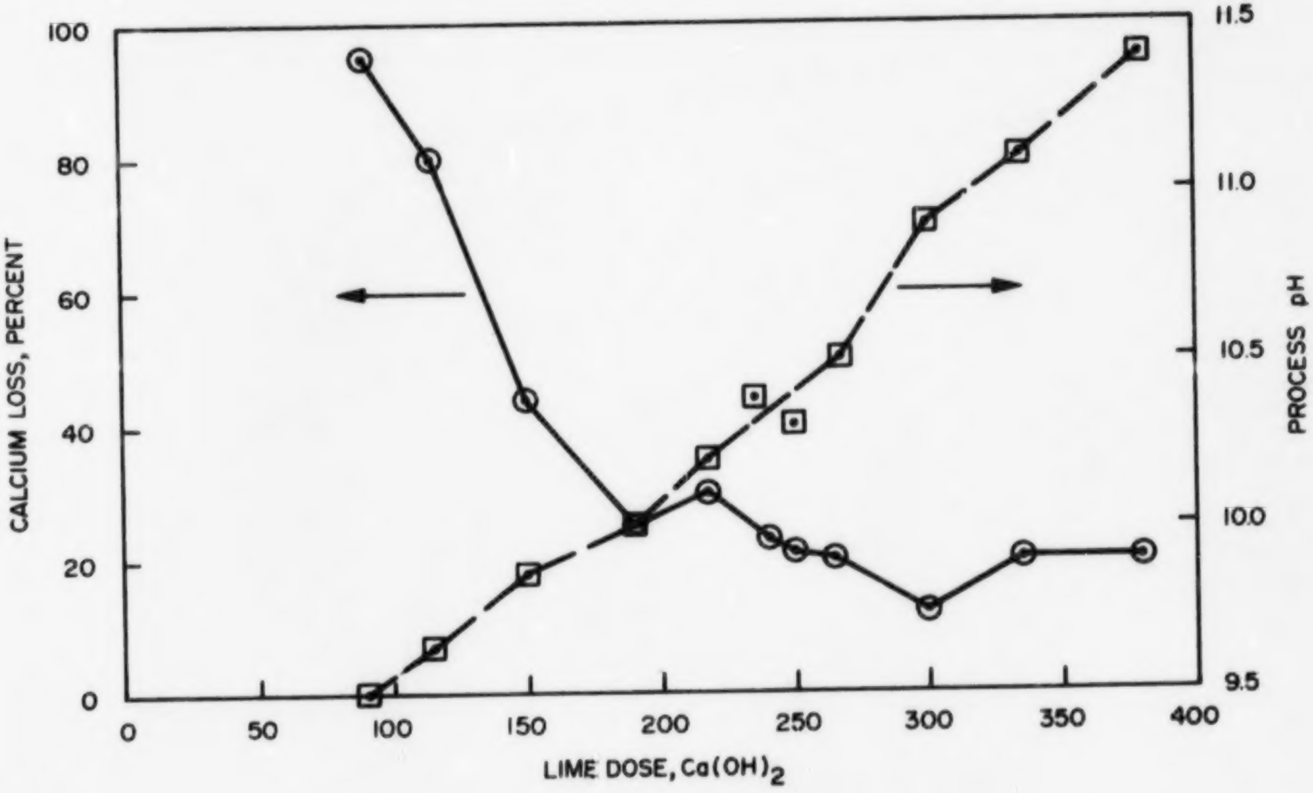


Figure 6-6 Calcium loss to supernatant and phosphorus precipitation

or plant scale testing. Cost and performance comparisons should dictate coagulant choice.

Hydrolysis

The discussion of lime treatment process chemistry would not be complete without mention of the concept of "hydrolysis". Certainly, no aspect of this subject is more controversial than the role of hydrolysis. Zuckerman and Molof[16] have theorized that, by managing the lime treatment stage, the downstream activated carbon treatment or activated sludge treatment can be optimized. The procedure suggested was that at high pH (11.5 in the wastewater studied) high molecular weight organics (e.g., MW $>$ 1200) are hydrolyzed to low molecular weight organics (MW $\sim$ 400). Zuckerman and Molof[16] concluded that high molecular weight organics are not efficiently adsorbed, whereas low molecular weight organics are. It has also been suggested that the activated sludge process would also benefit by hydrolysis in the chemical primary on the basis that low molecular weight organics are more easily and completely degraded.

No other investigators have documented or supported the "hydrolysis" concept as advanced by Zuckerman and Molof. In fact, reviewers and other researchers have made contrary conclusions. Weber,[17] in a discussion, questioned the character of the high molecular weight organics determined by the gel-permeation chromatography and wondered if they were in fact colloidal material. If they were really colloidal material, they could have been removed by coagulation rather than hydrolysis. Weber disputed the molecular weight concept as a determing factor in carbon efficiency for a number of reasons (see discussion). He also provided high pH data which showed no significant hydrolysis effect at a pH of 11.5. In a later discussion, Weber[18] concluded that hydrolysis-adsorption could not demonstrate any advantage in terms of effluent quality when compared to other physical-chemical effluents. McDonald, et al,[19] found very little high molecular weight material in raw wastewaters from various locations. The proportion of this material was always less than 10 percent, which is contrary to the findings of Molof and Zuckerman.[20] If there are essentially no high molecular weight materials present, there can be no benefit from their hydrolysis. Westrick and Cohen[21] found no benefit in high pH lime operation to carbon adsorber efficiency as compared to low pH lime operation or ferric operation. These findings are again contrary to the findings of Zuckerman and Molof.

The weight of evidence appears to be against the concept of hydrolysis as a significant effect in lime treatment of raw wastewater.

LIME ADDITION

Lime is added in sufficient quantity to increase the wastewater pH to the level required by the treatment process. The amount of lime needed is a function of wastewater flow, total alkalinity and calcium hardness. When lime is fed ahead of the primary clarifiers, the lime slurry should be added at a point of high turbulence in the wastewater. This turbulence can be created by a sudden drop in the hydraulic profile, as by passage of the liquid through a Parshall flume or over a weir, or may be produced by a mechanical agitator or mixer. The degree of agitation is more important than the mixing period. When using mechanical rapid mixers, scaling of the shaft and impeller is likely to occur. Also, unless removed, rags will tend to wrap around it. Therefore, to facilitate maintenance, provisions should be made for duplicate units.[22]

Where preaeration is provided for the removal of grit, the addition of lime ahead of the preaeration tanks could offer several advantages. When quicklime is used, the lime slakers do not require grit removers, since grit particles will settle in the preaeration tanks. This arrangement saves power, simplifies maintenance and provides a more compact equipment layout. The savings in space can be significant when paste type slakers are specified since, as was pointed out before, they require considerably less floor space than detention slakers.

Also, if the slakers can be located nearby or directly above the point of chemical application, the difficulties of slurry handling can be largely eliminated. Problems associated with the transport of lime slurries derive from the fact that the water in which lime is suspended, because of its high pH, undergoes a softening reaction with the precipitation of calcium carbonate. This forms a dense hard scale which in time will plug the solution lines.[23] At the wastewater treatment plant in Holland, Michigan, the lime slurry line has to be cleaned with a special polurethane tool ("Poly-Pig") every other day to keep it clear.[24] The scale also forms at the point where lime is added to the treatment process.[7]

Fig. 6-7 shows the 3600 kg/hr (8000 lb/hr) paste slakers in the CCCSD water reclamation plant[25] located above a steep channel. A hydraulic jump occurs in this channel when the rapidly moving flow encounters the horizontal water surface of the preaeration and flocculation tank. The turbulence created by the jump will be used to mix lime, ferric chloride and polymer with the raw wastewater.

CONTROL OF LIME DOSAGE

Lime dosage control is normally based on one or more of the following measurements: plant flow, influent pH and effluent pH. Because there is no correlation between wastewater flow and wastewater characteristics (e.g., BOD, suspended solids, alkalinity, and the like), it is generally recommended that one of the following three methods be used to control lime dosage to maintain a fixed pH level in the flocculation tank:

1. Influent flow and off-line measurement (i.e., periodic laboratory analysis of wastewater samples) of flocculator pH.

2. Influent flow and on-line measurement (i.e., continuous measurement by a pH sensor) or flocculator pH.

3. Influent flow and on-line measurement of influent and flocculator pH.

Fig. 6-8 (top) is an example of open-loop feeder control whereby the lime dosage ratio is automatically proportioned to the influent flow rate. The pH in the lime flocculator is manually measured at preset time intervals, and changes in the

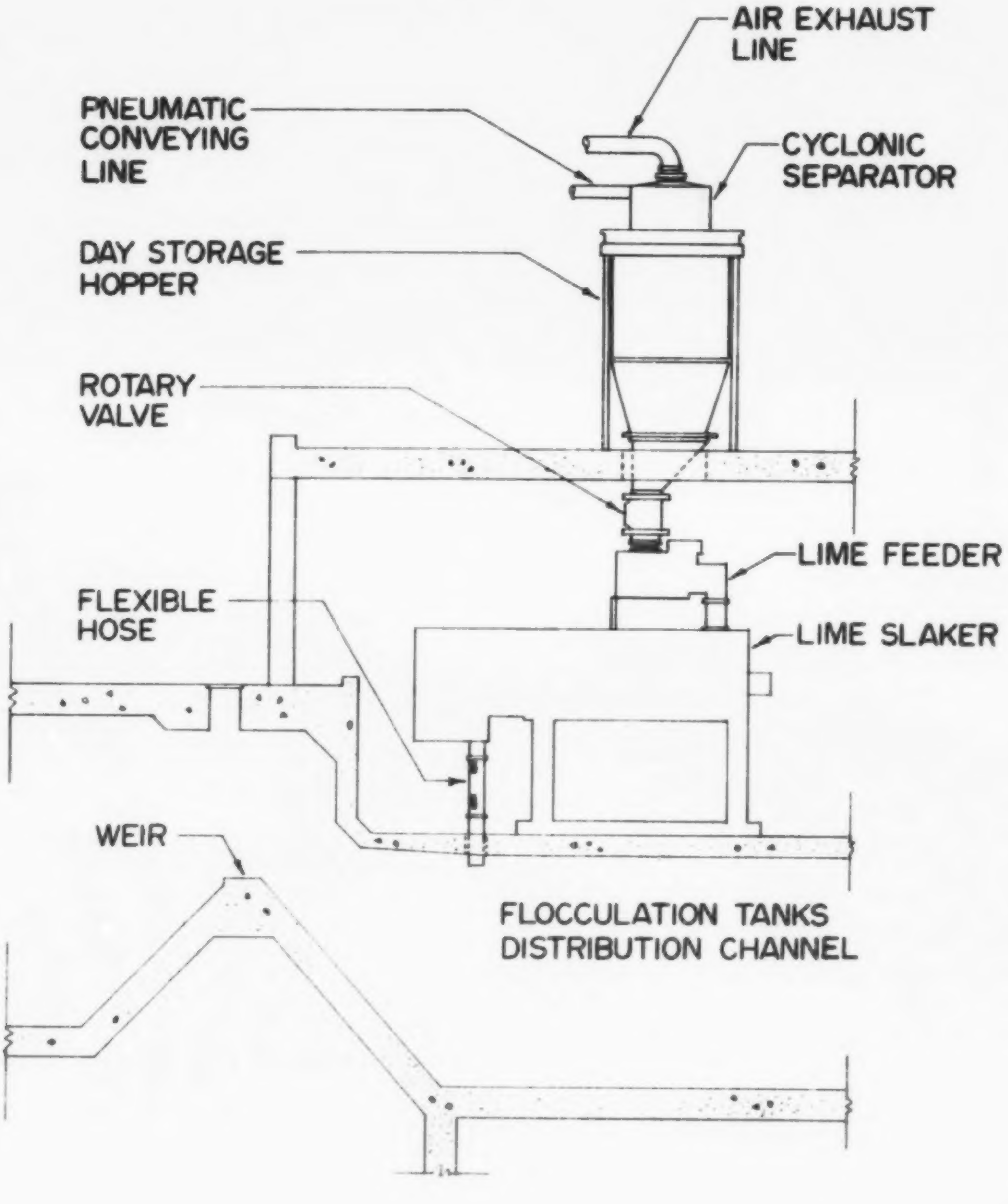
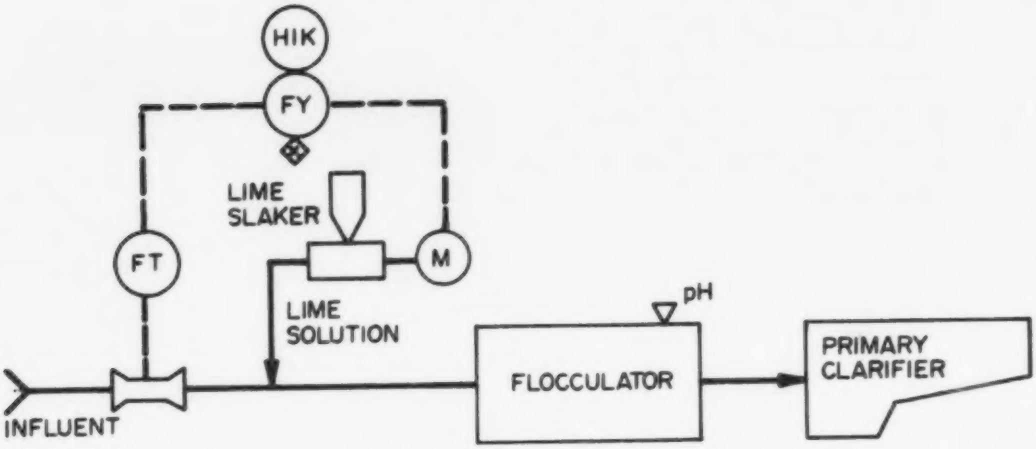

AIR EXHAUST LINE
PNEUMATIC CONVEYING LINE
CYCLONIC SEPARATOR
DAY STORAGE HOPPER
ROTARY VALVE
LIME FEEDER
FLEXIBLE HOSE
LIME SLAKER
WEIR
FLOCCULATION TANKS DISTRIBUTION CHANNEL

Figure 6-7 Location of lime slakers at the CCCSD water reclamation plant

INFLUENT FLOW & OFF-LINE FLOCCULATION pH


HIK
FY
LIME
SLAKER
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PRIMARY
CLARIFIER
INFLUENT

INFLUENT FLOW & ON-LINE FLOCCULALTION pH

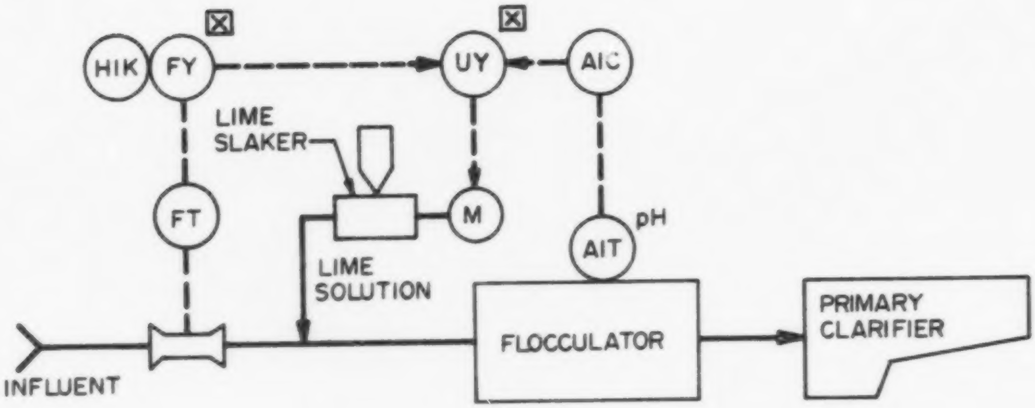
HIK
FY
UY
AIC
LIME
SLAKER
FT
M
pH
AIT
LIME
SOLUTION
FLOCCULATOR
PRIMARY
CLARIFIER
INFLUENT

Figure 6-8 Lime dosage control diagrams

dosage rate can be made by changing the setting on the ratio relay FY via manual loading station HIK. The control system shown in Fig. 6-8 (bottom) is an example of compound loop control whereby the dosage rate is proportional to flow, and the dosage controller AIC acts as a dosage trimming device, compensating for variations in lime demand as measured by the pH in the flocculator. Optimum dosage control is attainable with a feedforward control system with feedback trim. The feedforward portion of the control system is used to calculate the desired lime dosage per unit of influent flow based on the measurement of influent flow and pH. Although there is not a consistent relationship between influent pH and lime dose, the feedforward control action results in a first approximation to the required dosage.

The feedback controller is then used tc compensate for changes in wastewater characteristics that have not been taken into consideration in the feedforward calculation. In addition, the feedback controller also compensates for inaccuracies in the various transmitters and computing elements in the Control System. For the Control System shown in Fig. 6-9, the feedback controller AIC adjusts the ratio setting of ratio relay UY, if the feedforward prediction, executed through relay FY1, proves inaccurate as determined by the flocculator pH measurement.

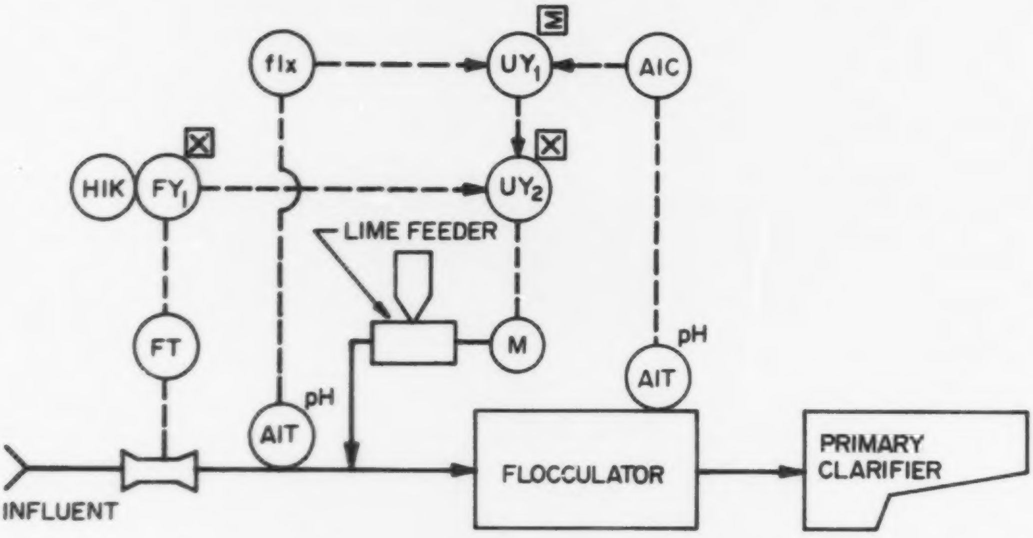

Figure 6-9 Lime dosage control diagram - feed forward control mode

Symbols in Figs. 6-8 and 6-9 follow Instrument Society of American's (ISA) Standard S5.1, Instrumentation Symbols and Identification. A comprehensive review of the principles of instrumentation and control and their practice in the wastewater treatment field is presented in reference 26.

FLOCCULATION

The unit process of flocculation is concerned with the aggregation of particles which have been destabilized in a preceding coagulation step. In a flocculation basin, opportunities for particle collision are provided by inducing fluid motion so that larger flocs can be produced and separated in a subsequent sedimentation step. Design considerations involve energy input (such as "G", the root mean square (rms) velocity gradient), detention time, degree of flocculator compartmentalization, and the type of shearing device (such as paddle design). Consideration must be given to floc breakup in addition to floc aggregation. In general, the rate of floc breakup varies with the level of turbulence. At high levels of turbulence floc breakup can predominate over floc aggregation.[27]

Flocculation design concepts have been investigated in detail for other waste and water treatment applications, but comparitively little work has been done with flocculation processes in wastewater treatment using lime as the coagulating agent. Parker and Niles[28] found that a preaeration-grit removal tank could be used for flocculation when lime was used as a coagulant. The currents caused by the release of diffused air in the grit removal tank encourage the formation of large flocculant particles which settled readily. By using air instead of mechanical means, the problems associated with rag fouling of mechanical flocculators were avoided. The same has not been found true when ferric chloride was used as the principal coagulant. Indications were that maximum particle aggregation was prevented due to floc breakup in the preaeration tank.[29]

When preaeration is used for flocculation, the coarse bubble air diffusers should be of the swing arm type to allow maintenance without having to take the tank out of service. Maintenance is required because of scaling inside the diffuser orifices, which is caused by carbon dioxide in the preaeration air. Monthly cleaning of diffusers may be required, although the maintenance period can be extended to as long as three months by providing a high pressure air or water connection for blowing out scale deposits.

Critical design criteria for flocculation in the preaeration tank are detention time and aeration rate. Detention time at average dry weather flow should be no less than 10 minutes and preferably 20 minutes for optimum results. The air supply to the preaeration headers should be separately regulated and provided with flow metering. Standard preaeration air requirements of 0.75 cu m per cu m (0.1 cu ft/gal) of sewage are adequate as a maximum delivery capability for low pressure air. While actual air usage has not been determined for applications such as at the ATTF, air rates for flocculation are normally set lower than for standard preaeration. Preliminary estimates indicate that air requirements may be lower than that normally used in preaeration. Care must be used to ensure adequate distribution of turbulence throughout the preaeration tank to prevent deposition of organics or chemical precipitation with the grit. A typical theoretical relationship (developed for the ATTF) between air rate and "G", the rms velocity gradient, is shown in Figure 6-10.

Mechanical means may also be employed for inducing the turbulent shearing necessary for flocculation. When mechanical means are employed, extreme care must be taken in the design and operation of devices used for rag removal. It has been found that when rags are screened, comminuted and then returned to the sewage, rag fouling problems develop. For instance at the Hatfield Township Plant, comminuted rags were found to reweave themselves and foul paddle-type flocculators.[30] Frequent maintenance was necessary. Rags have also fouled turbine-type flocculators and draft tubes in solids contact units, such as at the pilot plant at Salt Lake City.[31] To overcome this problem, it is recommended that rags be removed from the sewage after screening and disposed of separately when mechanical flocculation is to be employed.

Another aspect of flocculation concerns solids contact. In addition to aiding coagulation, solids contact promotes floc aggregation. Argaman and Kaufman showed that the rate of flocculation was proportional to the number of particles, the level of turbulence, "G", and the nature of the floc, in addition to other factors.[32] By increasing the solids concentration, flocculation efficiency may be enhanced.

Solids contact may be promoted by two means, solids recycle or integral recirculation in a "solids contact clarifier". Solids recycle has been used at CCCSD's ATTF to maintain the solids concentration between 900 and 3900 mg/l.[9] Solids recycle was accomplished by pumping a portion of the underflow solids back to the influent to the preaeration tank. Integral recirculation is described under primary clarifier design. Burns and Shell found that the solids level in the recirculation zone had to be limited to 4000 to 6000 mg/l to prevent prolonged contact and effluent deterioration due to septicity. Common detention times (based on influent flow) cited for the recirculation zone in a solids contact clarifier were given as 15 to 30 minutes.[12]

ALTERNATE PROCESSES FOR PRIMARY APPLICATION

Depending upon pH level, the addition of lime to raw wastewaters has resulted in three distinct processes, each of which is intended to achieve different degrees of basically the same objectives. These processes are: the Low Lime Process, the High Lime Process, and a process employing lime and other metal salts.

The low lime process normally operates in a pH range of 9.5 to 10.5. Phosphorus removals are lower than for the high lime process, since magnesium is not precipitated to coagulate the colloidal phosphorus. Solids and organics removal are also somewhat lower for the same reason.

The high lime process must operate at a pH of at least 10.5, so that magnesium precipitation can aid coagulation. While the lower limit of operating pH is given as 10.5, operation for most applications has usually been at 11.0 or even higher for a number of reasons that will be discussed in detail.

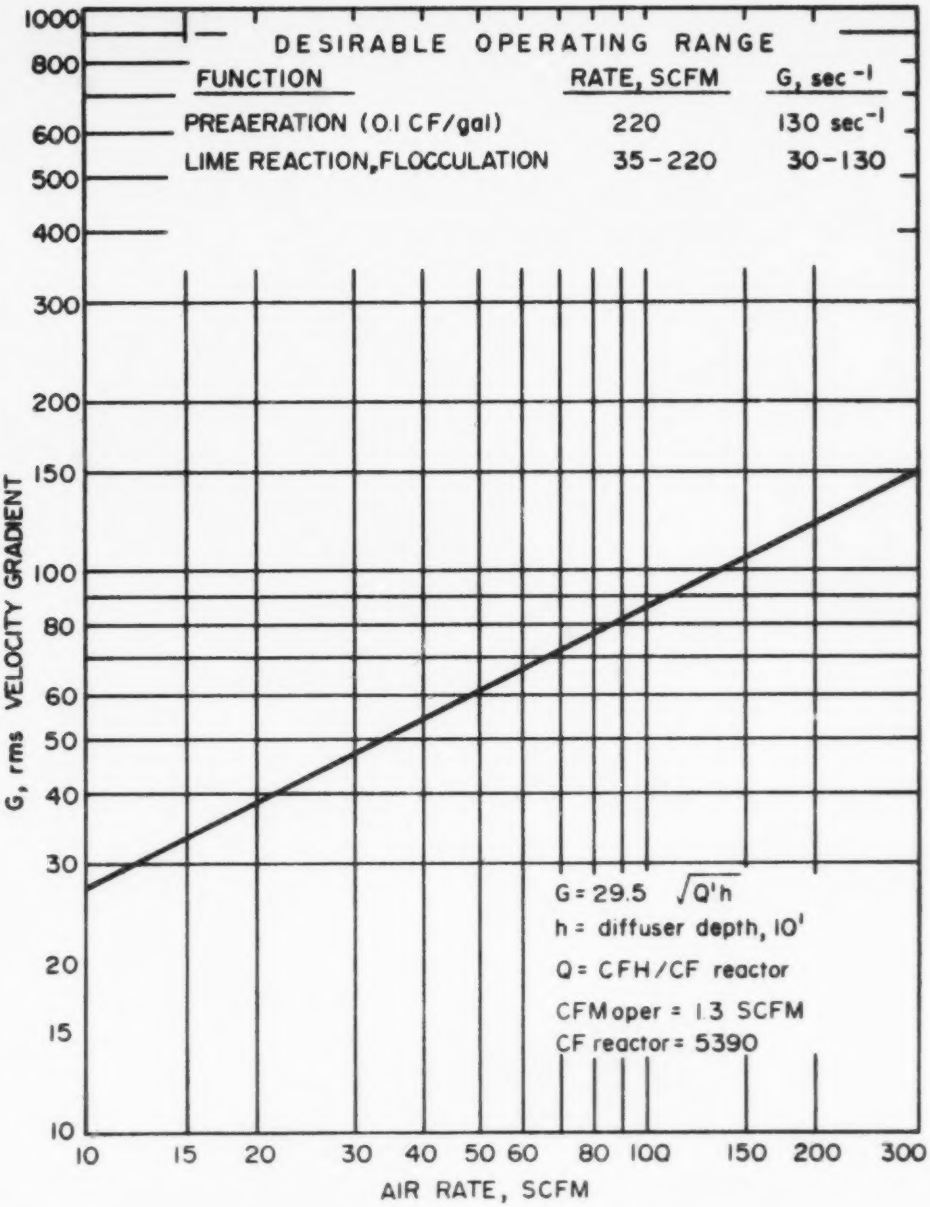

Figure 6-10 Air supply - shearing relationship for preaeration - flocculation

The third lime process is a relatively recent development. Lime is coupled with another metal salt, such as iron, to enhance the removal of phosphorus, organics and other solids. The metal salt permits production of a high quality effluent without the need to precipitate magnesium. As a result, lower lime doses are possible. Operating pH normally will be between 9.5 and 11.0.

Low Lime Process

The low lime process is a relatively economical method, from a chemical cost standpoint, to remove a large percentage of phosphorus from wastewater. Inspection of the data in Fig. 6-11 shows that beyond a given initial removal (eighty percent), the incremental amount of lime required to precipitate incremental quantities of phosphorus increases rapidly. If the desired level of phosphorus removal falls within the steeper portion of the curve, a relatively low dosage of coagulant will be sufficient. It can be observed that there is a minimum dose required before normal primary treatment removals are exceeded. As an example, in jar tests conducted by Tofflemire and Hetling[33] it was observed that 85 percent removal of phosphorus was obtained with a dosage of 125 mg/l of $Ca(OH)_2$ at pH 10. Albertson and Sherwood[4] reported similar results.

Figure 6-11 is derived from a pilot treatment study at Kansas State University[34] where the primary operation was at a low overflow rate of 12.2 cu m/day/sq m (300 gpd/sq ft). The allowable upper limits for overflow rate were not defined in the study. Lower phosphorus removals have been reported by Burns and Shell.[12] In one run, the removal was only 41 percent at pH 9.8, at 270 mg/l total alkalinity and a lime dosage of 270 mg/l as $Ca(OH)_2$.

The amount of lime required to precipitate phosphorus will normally cause coagulation also; therefore, suspended solids are removed along with phosphorus. Table 6-2 gives the results reported by Tofflemire and Hetling for approximately a month of clarifier operation at each pH value shown. Clarifier overflow rate was 16.3 cu m/day/sq m (400 gpd/sq ft). Coagulation aids have been used to increased the settling velocity and to flocculate insoluble phosphorus. The former is achieved by adding small dosages (lower than 1.0 mg/l) of organic polyelectrolites.[38]

Table 6-2. EFFECT OF PRIMARY CLARIFIER pH ON PERFORMANCE AT WATERFORD, NEW YORK

pH	CO[illegible] mg/l	Influent		Removals		Effluent Turbidity JTU
		COD % Sol.	S.S mg/l	COD %	S.S %	
9.9	542	40.9	240	60.7	76.3	36
10.3	548	25.5	356	69.5	88.5	20
10.8	782	23.1	548	75.6	91.0	27

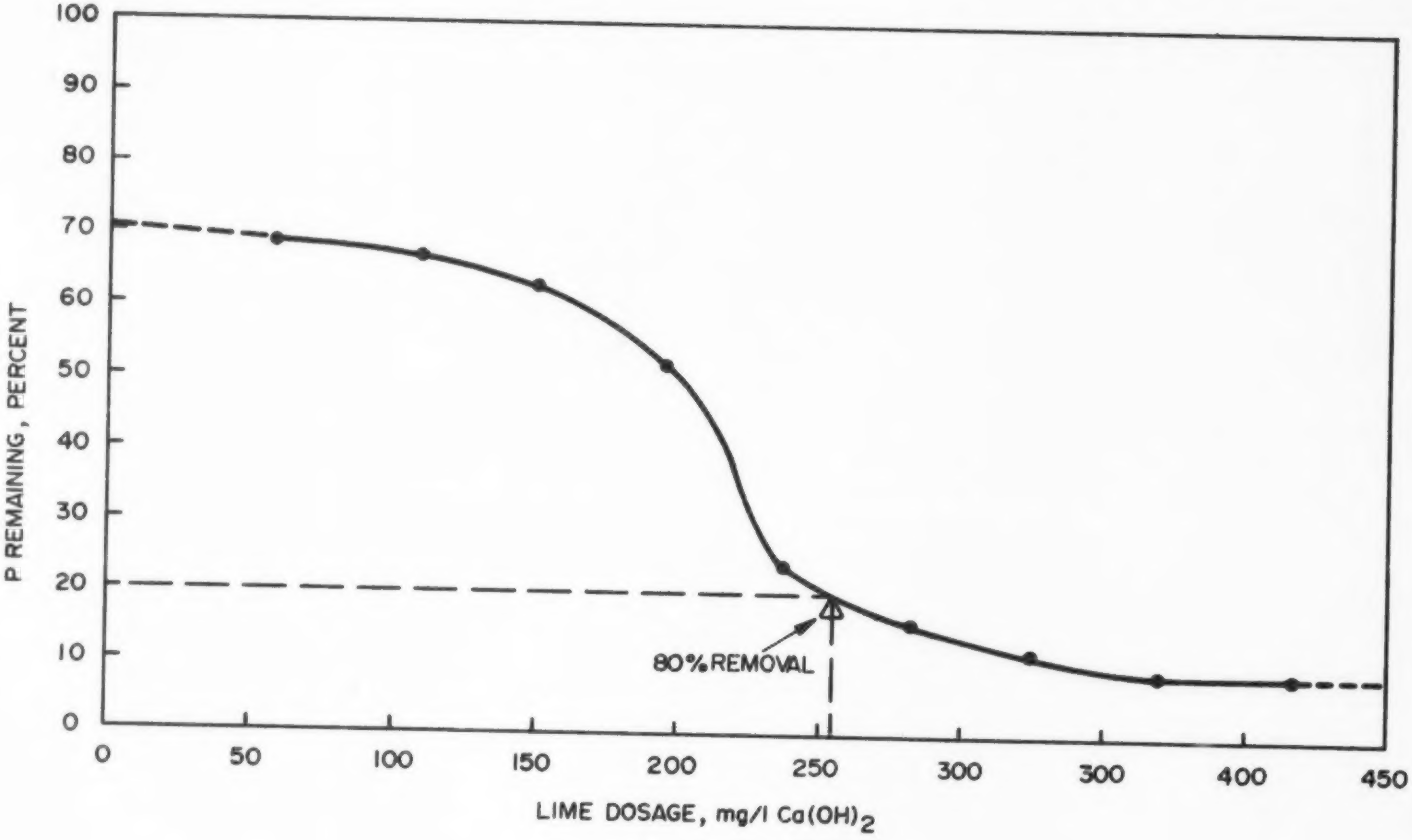

Figure 6-11 Phosphorus removal as a function of lime dose

Three full-scale plants (Holland, Mich.; Hastings, Mich. and Hatfield Township, Pa.), using the low lime process were surveyed in connection with this project. All of the plants were designed around the "PEP" process patented by Dorr-Oliver and feature sludge recirculation to the flocculator zone. Operating data for these plants are shown in Table 6-3. As can be seen, primary performance in two of the plants is low. This may be due to insufficient lime dose (see Fig. 6-11), or to excessive overflow rate.

In general, design overflow rate for low lime applications is fairly low and runs about 16-32 cu m/day/sq m (400-800 gpd/sq ft) at average dry weather flow. Dorr-Oliver recommendation for overflow rates at peak wet weather flow is 33 to 40 cu m/day sq m (800 to 1000 gpd/sq ft).

High Lime Process

When certain requirements on final effluent water quality demand raising the wastewater pH to 11 or 11.5, i.e., to increase lime dosages, the resulting process is called the High Lime Process. The figures given in Table 6-2 show the improvement in BOD (COD) and suspended solids removal with increased pH values. As was mentioned earlier, wastewater clarification in the high lime process is directly related to the removal of magnesium in the form of magnesium hydroxide. The reaction of magnesium with calcium hydroxide requires a pH greater than 10.5. Clarification is further enhanced by the precipitation of additional calcium carbonate which improves floc stability and settling characteristics.[39] The high lime process also aids in removing phosphorus, ammonia nitrogen (via air stripping) and certain viruses. Phosphorus removal as a function of lime dose approaches a logarithmic relationship. After the initial fraction is removed, further unit precipitation of phosphorus occurs with successively increasing lime dosage.

The efficiency of ammonia air stripping as a result of high lime treatment depends on the pH of the wastewater. The process requires a high pH to achieve efficient removal of ammonia, because this nitrogen compound is very soluble in water and is highly ionized at pH 7.0. The following table illustrates equilibrium conditions between ammonium hydroxide and disassociated ammonia at various pH levels:

pH	NH_4OH: NH_3
7.0	0.0055:1
8.0	0.055:1
9.0	0.55:1
10.0	5.5:1
11.0	55:1

Since only the undisassociated ammonium hydroxide can be removed by air stripping, the process is practical only at pH levels of 10.5 and higher.

Table 6-3. OPERATING PARAMETERS FOR PRIMARY TREATMENT IN "PEP" PLANTS

Plant	Present ADWF, cu m/d (mgd)	$Ca(OH)_2$ dose, mg/l	pH	Present ADW overflow rate, cu m/day sq m (gpd/sq f)	P removal, percent	SS removal, percent	BOD (COD) removal, percent	Reference No.
Hastings	3,030 (0.8)	297	9.6	29 (700)	68	71	58	35
Holland	15,140 (4.0)	166	9.3	21 (520)	34	44	(a)	36
Hatfield	8,320 (2.2)	394	9.5	16 (390)	58	45	77 (61)	37

(a) Not available

The removal of virus through high lime treatment appears virtually complete. Cooper, et al.[40] found that a pH of 11.0 resulted in no detection of inoculated polio virus Type I. Lower operating pH values resulted in detectable levels of virus. Other unit processes, such as activated sludge, sand filtration, and carbon adsorption did not completely remove the virus.

Table 6-4 summarizes the results obtained in the Contra Costa ATTF when operating in the high lime process. The table shows the high degree of organics removal possible when the high lime process is used. For comparison, results from a control primary are shown.

As increasing quantities of lime are added to the wastewater, recovery of the spent chemical by recalcination becomes economically attractive. Basically, calcination converts calcium in the lime sludge to calcium oxide. Calcium must be in the carbonate form for lime recovery to be a feasible process. As was mentioned earlier, it has been found that the pH has to be raised above 9.5 before calcium carbonate will begin to precipitate from the wastewater. Another factor is the alkalinity of the wastewater. In highly alkaline wastewaters, additional $CaCO_3$ will be precipitated at high pH levels. Therefore, for the same lime dosage, the flow at which lime recovery becomes feasible is smaller for plants treating a highly alkaline wastewater. Figure 6-12 illustrates the relationship between lime dosage and wastewater alkalinity in the high lime process.[41]

Lime and Other Metal Salts

The coupling of lime with other metal salts for wastewater coagulation is a fairly recent development. It derives from the practice in water softening plants, where metal salts are used in the recarbonation stage to improve the flocculation of the finely divided calcium carbonate precipitate. The first application of lime coupled with iron was reported by Wuhrman.[42] Iron (Fe^{+++}) was used at a dose of 1 to 2 mg/l as a flocculation aid to improve phosphorus precipitation in the pH range of 10.5 to 11.0. The lime was applied to secondary effluents. Wuhrman also noted that excess biological sludge could effectively be coprecipitated with the lime sludge. Lime has been coupled with alum in precipitation of oxidation pond effluents.[43] A pilot plant operated by the Napa County Sanitation District obtained 83 percent SS removal when operating at a pH of 10.8 the lime dose (as $Ca(OH)_2$) was 260 mg/l and was coupled with an alum dose (as $Al_2(SO_4)_3 \cdot 18H_2O$) of 50 mg/l. Bishop, et al.,[44] employed ferric chloride with lime at low-pH operation but has not reported the details.

Considerable experience has been gained at the Advanced Treatment Test Facility in the use of lime coupled with ferric chloride.[9] Results are summarized in Table 6-5. Comparing these results to those obtained with the use of lime alone (Table 6-4), it can be seen that there is relatively little difference in the removals obtained for the conventional parameters (BOD, SS, TOC). Moreover, it can be seen that the phosphorus removal obtained at pH 10.2 with iron, exceeds that obtained at pH 11.5 without iron. Chemical dose, is of course, appreciably less at the low pH. Further, there is approximately 28 percent less solids generation at pH 10.2 than 11.5.[45] Grease removal is also considerably better with lime and iron operation compared to lime alone.

Table 6-4 HIGH pH TREATMENT OF CCCSD WASTEWATER

Constituent (mean value)	pH 11.5 operation[a] Ca $(OH)_2$: 500 mg/l					pH 11.0 operation[b] Ca $(OH)_2$: 400 mg/l				
	Raw sewage	Control primary		Chemical primary		Raw sewage	Control primary		Chemical primary	
	mg/l	mg/l	% removed	mg/l	% removed	mg/l	mg/l	% removed	mg/l	% removed
BOD_5	190	103	46	50	74	192	121	37	60	69
SS	199	57	71	41	79	195	57	71	47	76
VSS	-	43	-	20	-	-	46	-	25	-
Turbidity	-	35[c]	-	16[c]	-	-	40[c]	-	26[c]	-
TOC	107	59	45	37	65	118	68	42	48	59
Soluble organic carbon	16	16	0	23.4	-46	17	21	-24	28	-65
Total phosphorus as P	9.4	-	-	0.96	90	9.2	-	-	2.3	75
Settleable solids	8.2[d]	0.3[d]	95	nil	100	9.5[d]	0.2[d]	98[d]	<0.1[d]	>99
Calcium hardness[e]	76	-	-	168	-	76	-	-	156	-
Magnesium hardness[e]	96	-	-	40	-	103	-	-	59	-
Hardness increase[e]	-	-	-	46	-28	-	-	-	36	-20
Grease	57	32	44	12	79	53	42	21	19	64

[a] December 22, 1971 to February 10, 1972, at average flow 1.30 mgd.

[b] February 11 to February 28, 1972, at average flow 1.12 mgd.

[c] JTU

[d] ml/l

[e] as $CaCO_3$

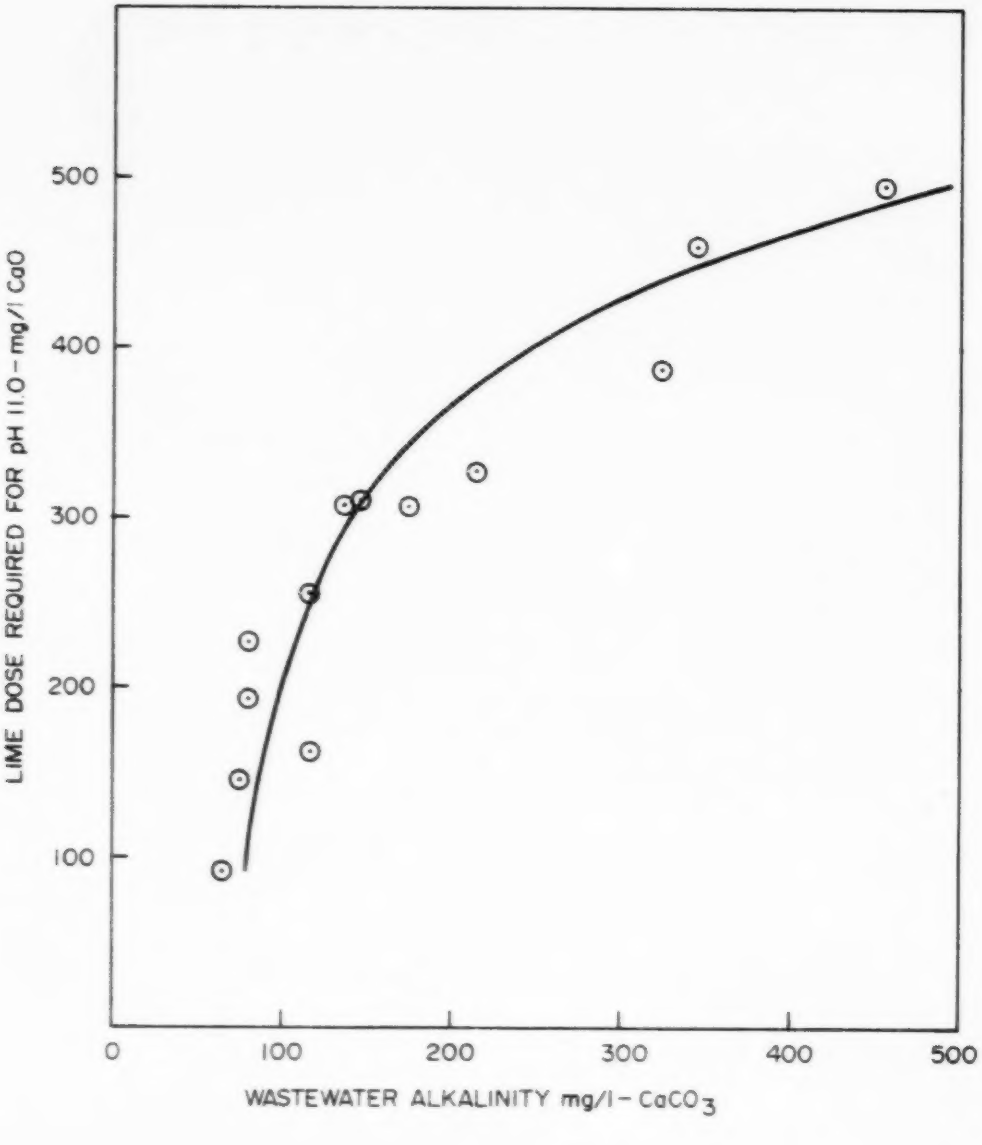

Figure 6-12 Lime requirement for pH 11 as a function of wastewater alkalinity

Table 6-5 LIME AND IRON TREATMENT OF CCCSD WASTEWATER

Constituent (mean value)	pH 11.0 operation[a] $Ca(OH)_2$: 400; $FeCl_3$: 14					pH 10.2 operation[b] $Ca(OH)_2$: 289; $FeCl_3$: 24				
	Raw sewage mg/l	Control primary		Chemical primary		Raw sewage mg/l	Control primary		Chemical primary	
		mg/l	% removed	mg/l	% removed		mg/l	% removed	mg/l	% removed
BOD_5	210	109	48	53	75	178	106	40	59	66
SS	305	69	78	27	91	235	59	75	31	87
VSS	-	49	-	14	-	-	48	-	19	-
Turbidity	-	45[c]	-	14[c]	-	-	41[c]	-	15[c]	-
TOC	130	72	45	37	72	117	68	42	43	63
Soluble organic carbon	23	18	21	24	-4	20	17	15	25	-25
Total phosphorus as P	9.5	-	-	0.85	91	9.4	-	-	0.68	93
Settleable solids	13.2[d]	0.13[d]	99	nil	100	12.1[d]	.1	99	<0.1[d]	>99
Calcium hardness as $CaCO_3$	75.5	-	-	139	-	72	-	-	148	-
Magnesium hardness as $CaCO_3$	90	-	-	32.5	-	90	-	-	70	-
Hardness increase as $CaCO_3$	-	-	-	6	-4	-	-	-	56	-34
Grease	146	-	-	9.5	94	66	-	-	8	88

[a] March 23, 1972 to April 5, 1972 at average flow 1.19 mgd.

[b] April 7, 1972 to April 30, 1972 at average flow 1.20 mgd.

[c] JTU

[d] ml/l

It is probable that future applications of lime to raw sewage coagulation will increasingly employ supplementary dosages of other metal salts because of the savings in chemical and solids handling costs.

RECARBONATION

Raising the pH of wastewater by lime will result in deposition of calcium scale on surfaces with which the water comes in contract. To prevent this the pH is adjusted downward to a value of about 7 by the addition of carbon dioxide (CO_2) after the wastewater leaves the lime treatment unit and before it undergoes other treatment processes (an exception involves ammonia stripping which requires high pH). The hydroxides and carbonates which have been produced in raising the pH are reconverted to bicarbonates according to the following reactions:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

$$CaCO_3 + CO_2 + H_2O \longrightarrow Ca(HCO_3)_2$$

Recarbonation is a process which has been used for many years in water treatment for downward adjustment of pH following lime-soda water softening. The recent increase in the use of lime for treatment of wastewaters has resulted in recarbonation being increasingly used in advanced waste treatment schemes.

Sources of Carbon Dioxide

There are three principal sources of carbon dioxide for recarbonation: (1) liquid carbon dioxide; (2) combustion of a fuel such as propane or fuel oil, and (3) stack gas from either a lime recalcining furnace or a sludge incineration furnace. In most waste treatment applications, the latter source is usually used. Stack gas from sludge incineration contains 8-14 percent carbon dioxide, and gas from a lime recalcining furnace contains 14-20 percent carbon dioxide.

It is interesting to note that at the CCCSD's ATTF sufficient carbon dioxide is normally supplied by the biological oxidation reactions in the nitrification units to lower the pH to the desired value as the wastewater enters the aeration tanks.[9] Liquid CO_2 is used on a standby basis when the pH in the aeration tanks becomes too high for efficient biological oxidation. When external carbon dioxide is required, it is added directly to the aeration tanks.

The quantities of carbon dioxide necessary for recarbonation can best be determined by laboratory tests. The best procedure is to bubble CO_2 into a sample of lime-treated wastewater under conditions likely to ensure nearly complete transfer efficiency; required dosage generally range from 200 to 400 mg/l. It is possible to compute directly the dose of carbon dioxide necessary to lower the pH to 8.3 (i.e., to change hydroxide and carbonate alkalinity to bicarbonate alkalinity) if the initial types and quantities of alkalinities present are known. An example of such a calculation is given by Culp and Culp.[46]

Recarbonation Equipment

Recarbonation equipment consists of a reaction basin for recarbonation to take place, equipment required to produce and deliver the carbon dioxide to the basin, and a diffusion system to add the carbon dioxide to the wastewater.

Regarding reaction basin design, it is important to note that the recarbonation reaction is not instantaneous. Although the CO_2 gas may enter the water as dissolved CO_2 rapidly, the time required for recarbonation reactions to be completed and the pH to be lowered to the desired value may be 10 to 15 minutes. Thus, sufficient detention time must be allowed in the basin or scale will form on the surfaces of downstream units and piping.

Design of the reactor also depends on whether the pH adjustment is made in one or two stages. When lime is used in tertiary treatment in high lime application, it is common practice to recarbonate in two steps. In the first step the pH of the wastewater is usually reduced to a value near 9.3. This is the point of minimum solubility of calcium carbonate in tertiary treatment applications. This calcium carbonate is then settled in the reaction basin and can be reclaimed by recalcining. At South Tahoe[11] about 17 percent of the lime which is recovered comes from the recarbonation settling basin. In the second step of the recarbonation process, the pH is brough down to about 7.0 to provide a stable effluent.

If two-stage recarbonation is used, sufficient detention time must be allowed to provide both reaction and settling in the first stage. Culp and Culp[46] recommend at least 30 minutes with an overflow rate of not more than 98 cu m/sq m/day (2,400 gal/sq ft/day). Provisions should be made for sludge removal in the settling basin. In single-stage recarbonation Culp and Culp recommend a detention time of at least 15 minutes. However, no provisions for settling and collection of sludge are required.

The equipment required to deliver the carbon dioxide to the reaction basin will depend on the source of the carbon dioxide.[46] If liquid CO_2 is used, it can be fed in either the gaseous or liquid form. In either case, pressure reduction cools the carbon dioxide as it is withdrawn from its insulated, pressurized storage container, and care must be taken to prevent dry ice formation. To prevent icing, storage containers are provided with means to heat the unit. For gas feed, an orifice plate in the feed line can be used to measure the flow. For liquid feed, equipment similar (except for materials) to solution-feed chlorinators may be used.

If fuel is burned to produce carbon dioxide, either underwater burners utilizing natural gas or pressure generators, which can burn a variety of fuels, are usually used. Pressure or forced-draft generators operate by compressing air and fuel in a chamber at sufficiently high pressure to allow discharge directly to the water after combustion. With underwater burners, air and natural gas are compressed and then burned at the point of application. When stack gas from a furnace is used as a source of carbon dioxide, the gas is passed through a wet scrubber to remove particulate matter and for cooling. The gas is then fed through a compressor in order to attain sufficient pressure to feed against approximately 2.4 m (8 ft) of water.

The type of diffusion system utilized will depend in part on the source of carbon dioxide. For example, underwater burners act both to produce carbon dioxide and to diffuse it into the wastewater; for liquid carbon dioxide, cotton fabric hose with controlled porosity may be used.

For dispersing gaseous carbon dioxide into the wastewater, commercial devices such as those manufactured by Walker Process or Lightnin (Mixing Equipment Co.) are available. These consist of a propeller mixer placed above a sparger through which carbon dioxide is added to the wastewater. The bubbles formed by such systems are quite small (on the order of 1 mm), and gas transfer efficiencies can range up to 90 percent. Culp and Culp described an absorption system consisting of a grid of perforated PVC pipe that is submerged 2.4 m (8 ft) in the wastewater. Transfer efficiencies of 85 percent or greater can be obtained with 4.7 mm (3/16-in) diameter holes that discharge 0.03 to 0.05 cu m/min (1.1 to 1.65 cfm) of gas. They recommend that the holes be spaced along the pipe at least 7.6 cm (3-in) apart, and that the pipes be spaced 0.46 m (1.5 ft) apart.

Since the recarbonation reaction takes considerable time and gas transfer can be accomplished fairly rapidly, it is often convenient to add gas only in the first portion of the reaction basin. However, this may result in incomplete transfer unless pure CO_2 is used. The concentration of CO_2 which can be dissolved in water depends on the partial pressure of CO_2 in the gas. For example, if stack gas is used, the equilibrium concentration of CO_2 in the wastewater may be less than the required dosage. In order to overcome this, it may be necessary to add carbon dioxide over a large fraction of the detention time, so that as carbon dioxide is removed from solution by the recarbonation reactions, more can be transferred from the gaseous phase into solution.

Single-Stage vs Two-Stage Recarbonation

When lime is applied to raw wastewater, it is doubtful that the recarbonation should be carried out in two steps, rather the pH be brought down to about 7 in a single step. Horstkotte, et al.,[9] found little difference in hardness where two-stage and single stage operations were compared during studies at the ATTF for pH less than 11.0. From this observation, it can be deduced that very little calcium carbonate precipitation will occur after first-stage recarbonation for most pH levels in the chemical primary. Studies at the Cleveland Westerly Plant[47] tend to confirm this conclusion. When the chemical primary clarifier was operated at pH 10.5, it was found that very little sludge was precipitated in the second-stage of 2-stage recarbonation. Calcium hardness across the clarifier was reduced only 6 mg/l. However, when the operating pH was raised to 11.5 to 12.0, large quantities of calcium carbonate were precipitated in the second of the two recarbonation stages. When single-stage recarbonation was practiced, no significant precipitation following recarbonation was observed. In Studies at Blue Plains, O'Farrell[48] found that two-stage recarbonation in raw sewage coagulation at a pH of 11.4 to 11.7 resulted in sludge production of 0.9 kg/cu m (7.5 lb/1000 gallons); when lime and iron were used at a pH of 10.5, only 0.4 to 0.5 kg/cu m (3.5 to 4.0 lb/1000 gallons) of sludge was obtained.

In summary, two-stage recarbonation appears to have a role to play only in tertiary treatment applications and in those few primary treatment applications where the pH is considerably above 11.0. Since effluents of the same quality can be obtained where lime, at lower dosages, is used in combination with other salts, two-stage operation at high pH is not economically justified. The latter process also produces greater quantities of sludge than lime coupled with metal salts.

TERTIARY APPLICATIONS

Lime use in tertiary treatment applications has been covered in detail in References 1, 11 and 46, based mostly on the experiences gained at the South Tahoe Water Reclamation Plant. The main advantages of the tertiary treatment approach are listed as greater flexibility of the operation because the biological and chemical processes are separated; and the separation of the organic, i.e., primary and secondary, sludges from the chemical ones, which tends to facilitate subsequent handling of the sludge and prevent the build up of inerts if lime recovery is practiced. It was acknowledged that the principal drawback of tertiary treatment was its high initial cost.

Although a comparison between the two lime processes is beyond the scope of this manual, it should be pointed out that two years of operation at the CCCSD's ATTF have demonstrated the stability of a biological system, i.e., nitrification-denitrification, following the addition of lime to raw wastewaters. The test facility also showed that combined sludges can be effectively classified with a solid bowl centrifuge, thereby minimizing the problem of recycling inerts. (See also Section VIII).

DESIGN CONSIDERATIONS FOR PRIMARY CLARIFIERS

When lime (or any other chemical) is added to raw wastewaters to increase the removal of suspended solids, phosphorus and toxic materials, the unit operations required are similar to those found in water treatment plants, i.e., rapid mixing, flocculation, sedimentation and sludge handling. These four processes have often been integrated into a single unit resulting in the upflow solids contact clarifier or sludge blanket clarifier. In connection with water treatment, it has been stated that the main advantage of this design, when compared to the separate tank approach, is its lower construction cost. Another important feature of the solids contact tank is the ability to bring the raw wastewater in contact with high concentrations of suspended solids. Figure 6-13 shows a typical solids contact unit.

It has often been stated that solids contact units are lower in capital cost than primary sedimentation tanks. However, detailed examination of this in Section XII shows that there is no economic advantage to solids contact units. It has now been common practice for many years to provide grit chambers ahead of the main treatment units[49] to protect mechanical equipment and, when sludge digestion is practiced, to prevent grit accumulation in the digestion tanks. Therefore, grit removal facilities are usually required and, preferably, precede the primary clarifiers. As mentioned earlier, a preaeration and grit removal tank can perform well as a flocculation basin. This flocculation can be provided with conventional primary tanks at no extra cost if preaeration is used for grit removal. In comparison, the solids contact unit must have previous grit removal so that the functions of flocculation and grit removal cannot be combined.

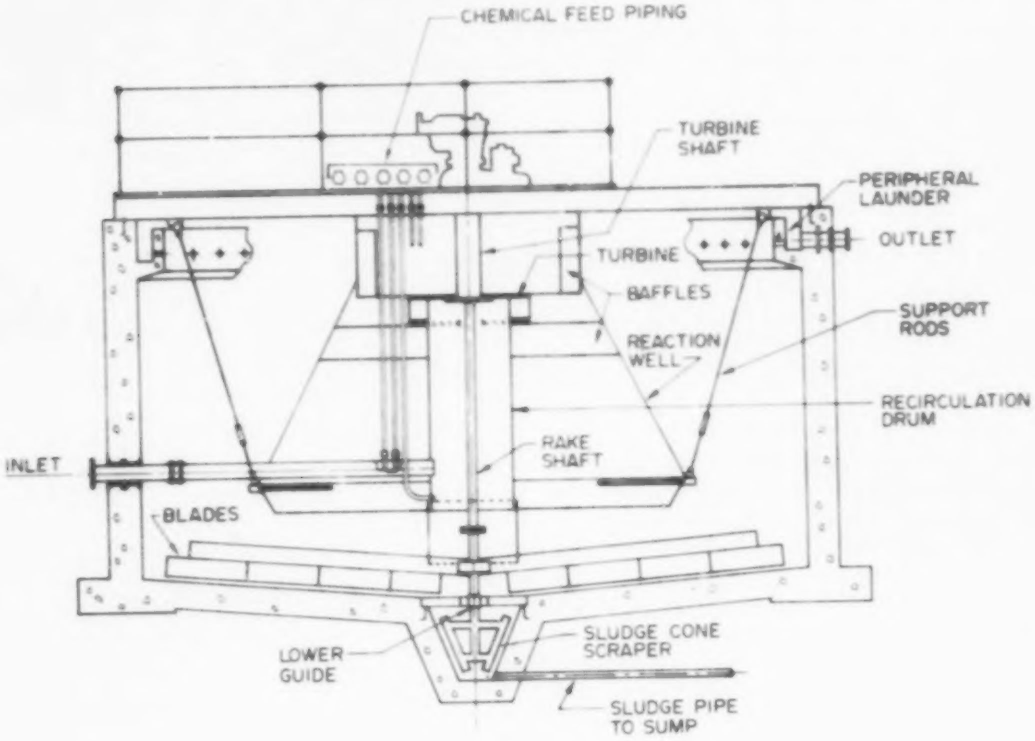
CHEMICAL FEED PIPING
TURBINE SHAFT
PERIPHERAL LAUNDER
OUTLET
TURBINE
BAFFLES
SUPPORT RODS
REACTION WELL
RECIRCULATION DRUM
RAKE SHAFT
INLET
BLADES
SLUDGE CONE SCRAPER
LOWER GUIDE
SLUDGE PIPE TO SUMP

Figure 6-13 Typical solids contact clarifier

(courtesy of the Eimco Corporation)

In lieu of grit removal tanks and a pumped grit slurry system, effective grit separation can be accomplished by degritting the primary sludge. With this system relatively thin primary sludge is pumped to centrifugal cyclonic separators. The grit separators would discharge the heavier, inorganic particles to a grit classifier with both the classifier and centrifugal separator overflowing to a sludge sump. Sludge would then be pumped from this sump to the thickening tanks. Although lower in first cost than separate grit removal tanks, disadvantages of sludge degritting include increased odor production because of an open classifier and sludge sump, plus more difficult maintenance of grit separation equipment due to the higher concentrations of organic material which may cause fouling of the equipment. The lower sludge concentration also requires larger thickening tanks, which offsets some of the cost savings of sludge degritting.

Culp and Culp[46] have also pointed out that sludge blanket clarifiers are difficult to control under varying flow rates or changing physical and chemical composition of the wastewater. Another operational problem in certain upflow clarifiers, when used in primary lime applications, is the tendency of rags and similar materials to wrap around the flocculator paddles. Shuckrow and Bonner,[46] based on pilot plant studies at the Westerly WTP in Cleveland, have recommended against the use of solids contact units for the full-scale plant. They found severe difficulties in maintaining a sludge blanket in the clarifier and stated that this problem would be further aggravated under variable hydraulic loadings.

Burns and Sheil have reported stable operation of a solids contact clarifier.[12] This was a solids contact operation and not sludge blanket clarification operation; this kept sludge out of the clarification zone. Sludge was kept at or below the bottom of the reaction well (Fig. 6-13).

Conventional primary sedimentation basins are commonly of circular or rectangular cross section, although some equipment manufacturers offer a square tank design. Fig. 6-14 shows a typical section of the chemical primary treatment units designed for the CCCSD Water Reclamation Plant.[25] A compact layout has been provided by the common wall construction of rectangular tanks and by the separation of the flocculation and sedimentation tanks by the distribution channel over an equipment gallery. The gallery houses the grit, sludge and scum pumps, the preaeration blowers and the associated pipine and appurtenances. The primary sedimentation tank in the ATTF has two basic functions: separation of the solids from the liquid and thickening of the solids. While the water reclamation plant under construction will incorporate separate thickening stages, considerable thickening takes place in the primary sedimentation tank itself.

From the surface of the ATTF tank the sludge could be seen to settle out very rapidly. Sludge profiles taken along the bottom confirmed that the bulk of the sludge settled out in the first three-eighths of the primary tank. Expansion of the sludge layer into the effluent end of the primary tank was taken as evidence of sludge thickening failure, since no significant increase in underflow solids concentration occurred at the time of layer expansion. On this basis, it is estimated that only 50 percent of the tank floor is effective in thickening.

Whenever sludge intruded under the effluent weirs or beyond, large flocs immediately began appearing in the effluent. As long as the sludge layer was held in the first half of the tank, no large flocs appeared. This factor helps explain the observed stability of these clarifiers as a function of overflow rate. Little deterioration in effluent quality occurred up to a maximum hourly overflow rate of 90 cu m/day/sq m (2200 gpd/sq ft). During these tests, the average dry weather overflow rate was 59 cu m/day/sq m (1440 gpd/sq ft). The detention time at the peak rate of flow was only 0.9 hours. The good separation of thickening and clarification functions in the conventional rectangular primary allows relatively high overflow rates to be obtained.

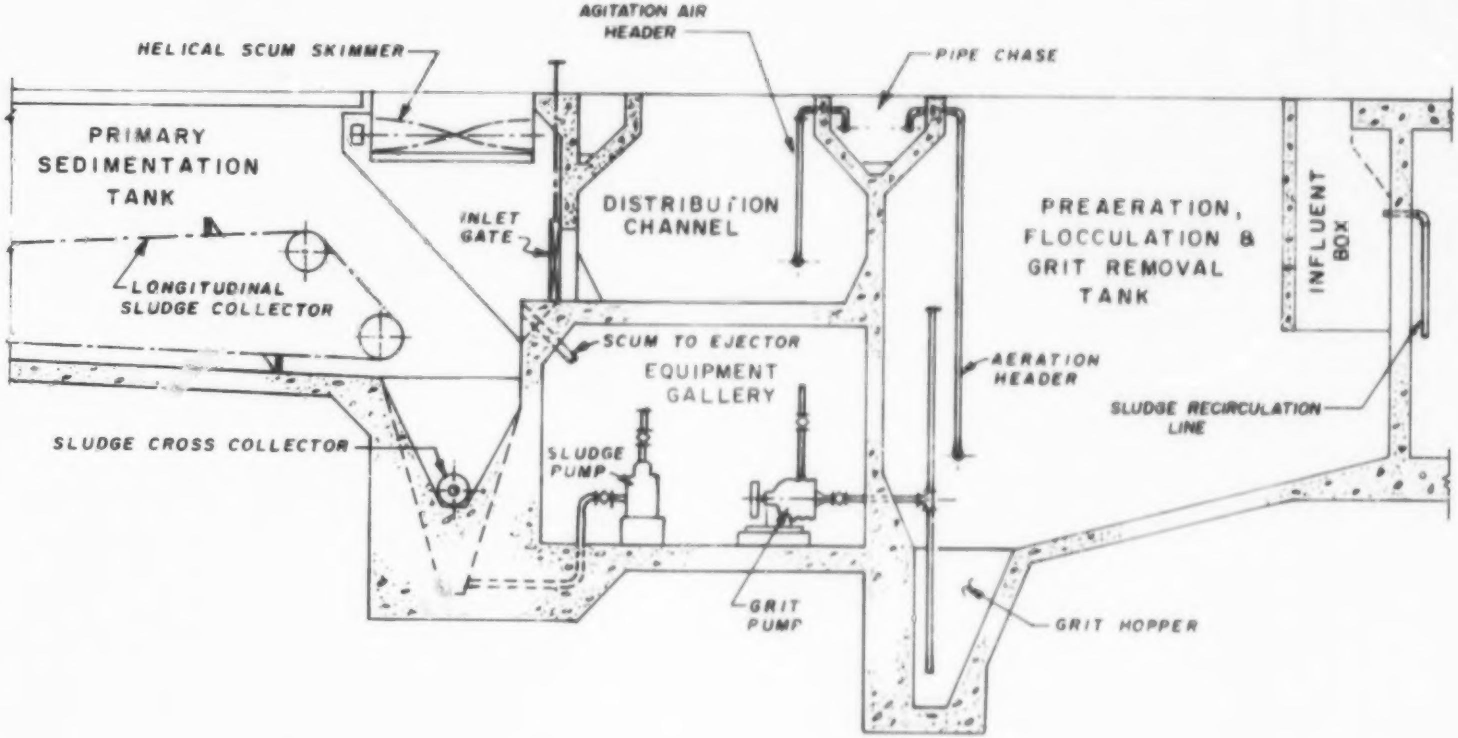
HELICAL SCUM SKIMMER
AGITATION AIR HEADER
PIPE CHASE
PRIMARY SEDIMENTATION TANK
INLET GATE
DISTRIBUTION CHANNEL
PREAERATION, FLOCCULATION & GRIT REMOVAL TANK
INFLUENT BOX
LONGITUDINAL SLUDGE COLLECTOR
SCUM TO EJECTOR
EQUIPMENT GALLERY
AERATION HEADER
SLUDGE RECIRCULATION LINE
SLUDGE CROSS COLLECTOR
SLUDGE PUMP
GRIT PUMP
GRIT HOPPER

Figure 6-14 Primary treatment units at CCCSD water treatment plant

The degree to which sludge could be thickened was affected by process pH. At pH 11.0 and above when lime alone was added to the primary, the sludge could be thickened to as much as 9 or 10 percent total solids (TS). However, at about 7 percent total solids and above, coning and bridging occurred in the sludge hoppers, and septic sludge zones developed. This problem can be minimized by designing steeper hoppers and providing positive feeding of sludge to the suction line of the sludge pumps. When the pH was dropped to 10.2, "thinner" sludges were obtained. The sludge could not be thickened to greater than 4.2 percent TS. However, when an anionic polymer coagulant aid was employed at a dose of 0.25 mg/l, 6.0 percent TS was attained in the underflow. Burns and Shell[12] have reported on the solids content of sludges over a slightly different pH range. At pH values above 11.5, the lime sludge thickening properties were significantly poorer than at pH 10.5 to 11.0.

Table 6-6 and 6-7 give maximum and recommended design parameters respectively to size primary clarifiers of both solids contact and rectangular design. The rectangular tank design for which these figures are applicable is that which is depicted in Fig. 6-14. Other rectangular tank designs may have differing limiting overflow rates and caution should be used in establishing design overflow rates unless specific test data is available. While solids contact type units are designed at approximately the same surface overflow rates as conventional rectangular primary tanks, considerably longer hydraulic retention times are employed. This translates into the need for deeper tanks when solids-contact units are designed. Even considering the separate preaeration and grit removal tank (at 20 minutes retention) as an addition to conventional tank cost, solids-contact units require greater structure size and therefore greater cost.

Table 6-6 MAXIMUM CLARIFIER DESIGN PARAMETERS

Flow	Rectangular tank		Solids contact clarifier[b]	
	Overflow rate cu m/d/sq m (gpd/sq f)	Detention time, hours	Overflow rate cu m/d/sq m (gpd/sq f)	Detention time, hours
Average dry weather (ADWF)	59 (1,440)	1.3	44 (1,080)	2.5 - 3.0
Peak dry weather (PDWF)[a]	90 (2,200)	0.9	73 (1,800)	1.5 - 2.0

[a] Peak flow during dry weather of 1 - 2 hour duration.

[b] Based on Reference 38.

It should be noted that Tables 6-6 and 6-7 apply to an operating pH of equal to or greater than 10.5. For both types of clarifiers, the design data are for highly buffered wastewaters (alkalinity 200-300 as $CaCO_3$). Low alkalinity wastewater would result in lower calcium carbonate precipitation and different, as yet undefined, criteria would apply. Criteria for low lime applications are not as well defined and were briefly discussed in a preceding section.

Table 6-7 RECOMMENDED CLARIFIER DESIGN PARAMETERS

Flow	Rectangular tank		Solids contact clarifier	
	Overflow rate cu m/d/sq m (gpd/sq ft)	Detention time, hours	Overflow rate[b] cu m/d/sq m (gpd/sq ft)	Detention time, hours[c]
Average dry weather (ADWF)	49 (1,200)	2.2	24 - 41 (580 - 1,010)	1.4 - 2.8
Peak dry weather (PDWF)[a]	73 (1,800)	1.4	-	-
Peak wet weather (PWWF)	147 (2,400)	0.7	76 (1,870)	1.4 - 1.9

[a] Peak flow during dry weather of 1 - 2 hour duration.

[b] Based on Reference 12.

[c] Proportioned from Table 6-6.

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SECTION VII

LIME SLUDGE THICKENING AND DEWATERING

GENERAL CONSIDERATIONS

Sludge thickening and dewatering are preparation or pretreatment steps which normally precede further sludge processing or final disposal. In wastewater treatment, thickening and dewatering have often been considered as different types of processes; in fact, thickening is a dewatering process. As currently applied, however, sludge thickening implies solids concentration with the aim of reducing the volume of sludge to be handled in subsequent treatment steps. Dewatering implies further removal of water, generally by mechanical means, to produce a relatively dry sludge cake for further treatment or disposal.

Land methods of sludge dewatering have not been included in this section, since in the majority of applications, they constitute the ultimate method of sludge disposal. For a discussion of ultimate disposal of ash, see Section XI.

SLUDGE THICKENING

Although sludge thickening is a preliminary process, it removes a major amount of liquid from the sludge. The curves presented in Fig. 7-1 show the reduction of water content under varying degrees of thickening. For example, when the sludge concentration is increased from 1.5 to five percent, over 70 percent of the original moisture is removed.

Two methods are commonly used to thicken sludge - gravity and air flotation. In general, the gravity method is used to thicken primary sludges; i.e., sludges that settle readily, while air flotation is employed when dealing with the lighter biological sludges.

A third thickening method, using centrifugal equipment,[1,2] is gaining acceptance, generally as an alternative to dissolved air flotation. When centrifuges are applicable, their use results in considerable savings in floor space requirements. Power costs, however, are likely to be higher than with gravity or air flotation thickeners.

Gravity Thickening

The results obtained at the CCCSD's ATTF in terms of thickening in the primary clarifiers lead to the conclusion that gravity thickening has clear advantages when dealing with the heavy lime sludges generated from primary treatment applications.[3] This process is not only simple to operate but also more economical than dissolved air flotation or centrifugation.

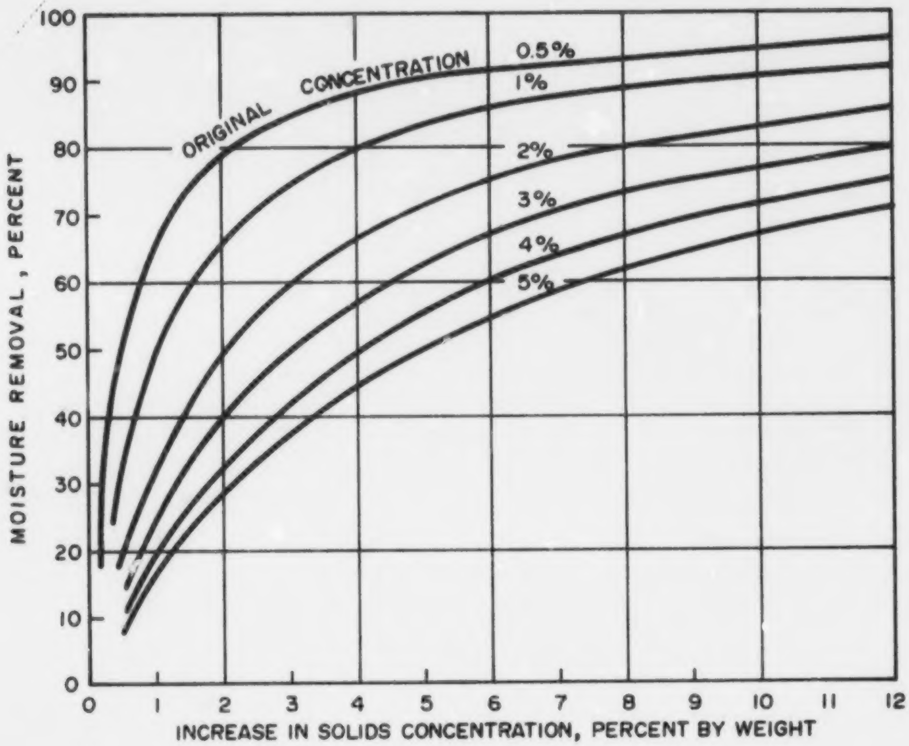


Figure 7-1 Relationship between increase in solids concentration and moisture removal (after Katz (12))

Scant information is available on gravity thickening of primary lime sludge. Black and Lewandowski conducted a three-month plant scale operation at Richmond Hill, Ontario, where lime sludge concentrations of up to 12 percent solids were achieved in gravity thickeners.[4]

Burns and Shell[5] have reported the results of eight months of laboratory thickening tests at pH values between 9.8 and 11.6. From these results they conclude that "the moderate treatment pH (below 11.0) sludges tested were generally more concentrated than the high treatment pH sludges (above 11.5)." Burns and Shell also stated that "it appears that the more concentrated the chemical clarifier underflow (initial solids) the more the solids can be concentrated." During the same work, Burns and Shell also evaluated the effect of polyelectrolytes as flocculation aids on thickener performance. They concluded that, although the continuous use of polyelectrolytes solely to reduce the thickener size was probably unjustified, the addition of chemicals would maintain a high underflow concentration under decreasing feed solids concentration.

At the time this report was being prepared, Burns and Shell were reevaluating their projections for thickener performance. A compression zone analysis indicated that to obtain ultimate sludge concentration (18-25 percent TS), thickener solids loading would have to be reduced below 49 kg/sq m/day (10 lb/sq ft/day), which is considerably lower than the 196 - 245 kg/sq m/day (40 - 50 lb/sq ft/day) previously recommended.[5] This came to light when they found that the results obtained in the laboratory tests could not be reproduced in a 2.4 m (8 ft) diameter gravity thickener.[6,7] Thickener performance was erratic, varying from no additional concentration to about 35 percent increase in the feed solids concentration. The concentration of feed solids ranged from 8.1 to 12.0 percent TS. Average thickener loading was 78 kg/sq m/day (16 lb/sq ft/day). The most recent recommendations on the design of gravity thickeners based on the work at Salt Lake City are included in Reference 8.

Investigators at EPA's Blue Plains pilot plant have conducted tests on the thickening properties at high lime sludge.[9] Interfacial settling velocity as a function of total solids concentration is shown in Fig. 7-2. Essentially, no differences in settling rates were observed between cases where recalcined lime was used and where only new lime was used. Using a batch flux method of analysis, it was concluded that with a solids loading of 673 kg/sq m/day (138 lb/sq ft/day), 10 percent underflow solids could be obtained. Similarly, at a solids loading of 430 kg/sq m/day (88 lb/sq ft/day), it was calculated that 20 percent total solids in the underflow could be obtained. The investigators cautioned, however, that **this data had not been verified in continuous thickening tests**.

Gravity thickeners are commonly deep circular tanks provided with a rotating arms mechanism for sludge agitation and collection. The feed sludge is introduced into a circular influent well and the overflow is usually collected over peripheral weirs. The thickened underflow forms a sludge blanket so the unit performs not unlike a solids contact clarifier. Sludge is withdrawn, continuously or intermittently, from a centrally located bottom hopper. A typical section of a gravity thickener is shown in Fig. 7-3.

To prevent septic conditions in the thickener, the use of chlorine has been recommended. The dosage should produce a residual chlorine concentration of 0.5 to 1.0 mg/l.[2] Low pressure air has also been used to prevent septicity. The gentle agitation provided by the compressed air also aids in promoting solids concentration by allowing entrapped water to escape through the sludge blanket.[10] This approach is seen in Fig. 7-4, which shows a cross section of the lime sludge thickener at the CCCSD water reclamation plant.[11] A 20-ft deep existing digester is being converted into a thickening tank. Design loading is 390 kg/sq m/day (80 lb/sq ft/day) and the lime sludge will be fed at an approximate concentration of 6 percent TS. Compressed air can also be used to fluidize the sludge blanket to control maximum solids concentration and to allow low-torque starting of the rotating arms.

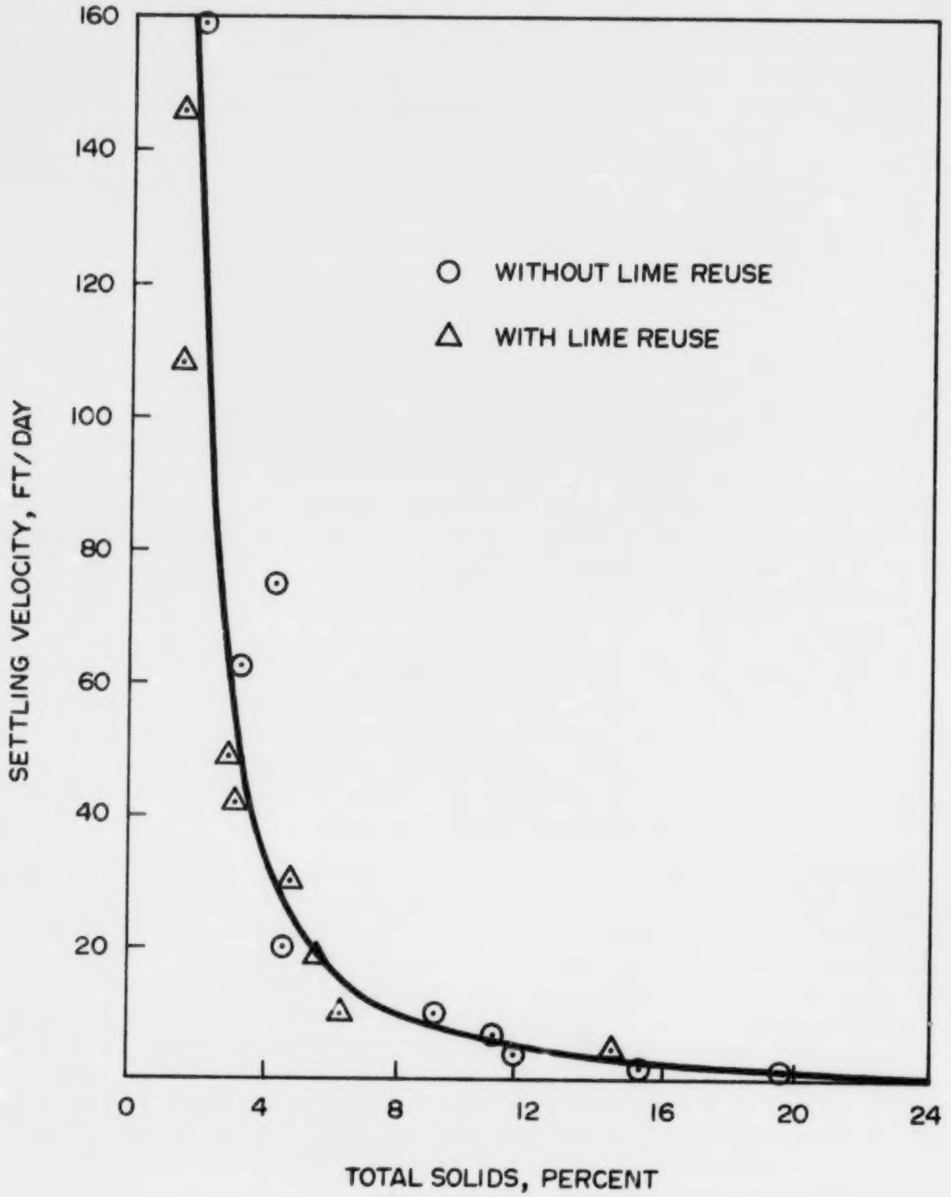


Figure 7-2 Settling characteristics of high lime sludge at the Blue Plains pilot plant

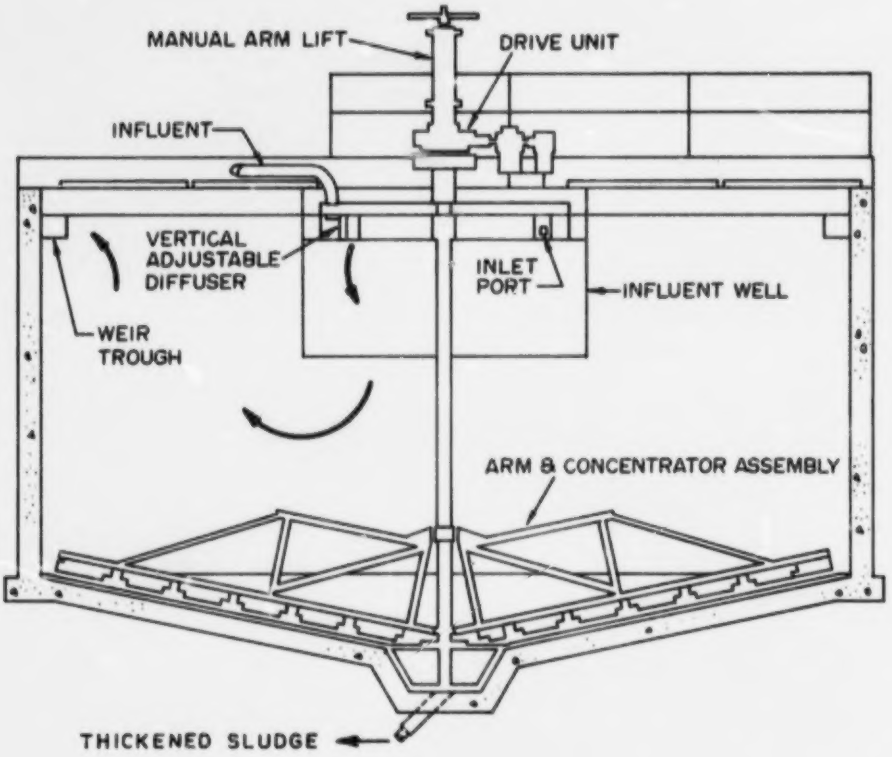

MANUAL ARM LIFT
DRIVE UNIT
INFLUENT
VERTICAL ADJUSTABLE DIFFUSER
INLET PORT
INFLUENT WELL
WEIR TROUGH
ARM & CONCENTRATOR ASSEMBLY
THICKENED SLUDGE

Figure 7-3 Typical gravity thickener (courtesy of Walker Process)

Although the concentration of solids that takes place in the primary sedimentation tank (see Section VI) could justify eliminating separate gravity thickeners, the latter also perform as sludge flow equalization basins. This function is as important as solids concentration to smooth out the flow of solids to downstream treatment processes. Since sludge production varies during the day, removal from the primary clarifiers is normally intermittent to insure that only well compacted sludge is withdrawn. The presence of thickeners then allows a fairly constant sludge feed to the centrifuges or furnaces which is essential for steady state operation. It is under steady state conditions that the dewatering and incineration equipment can achieve peak performance.

Surface skimming has not always been employed on gravity thickening tanks. Surface skimming has been found to be mandatory on tanks receiving centrate from a centrifuge classification step at the CCCSD's ATTF. (See a later discussion of classification in this section). The centrifuge operation caused

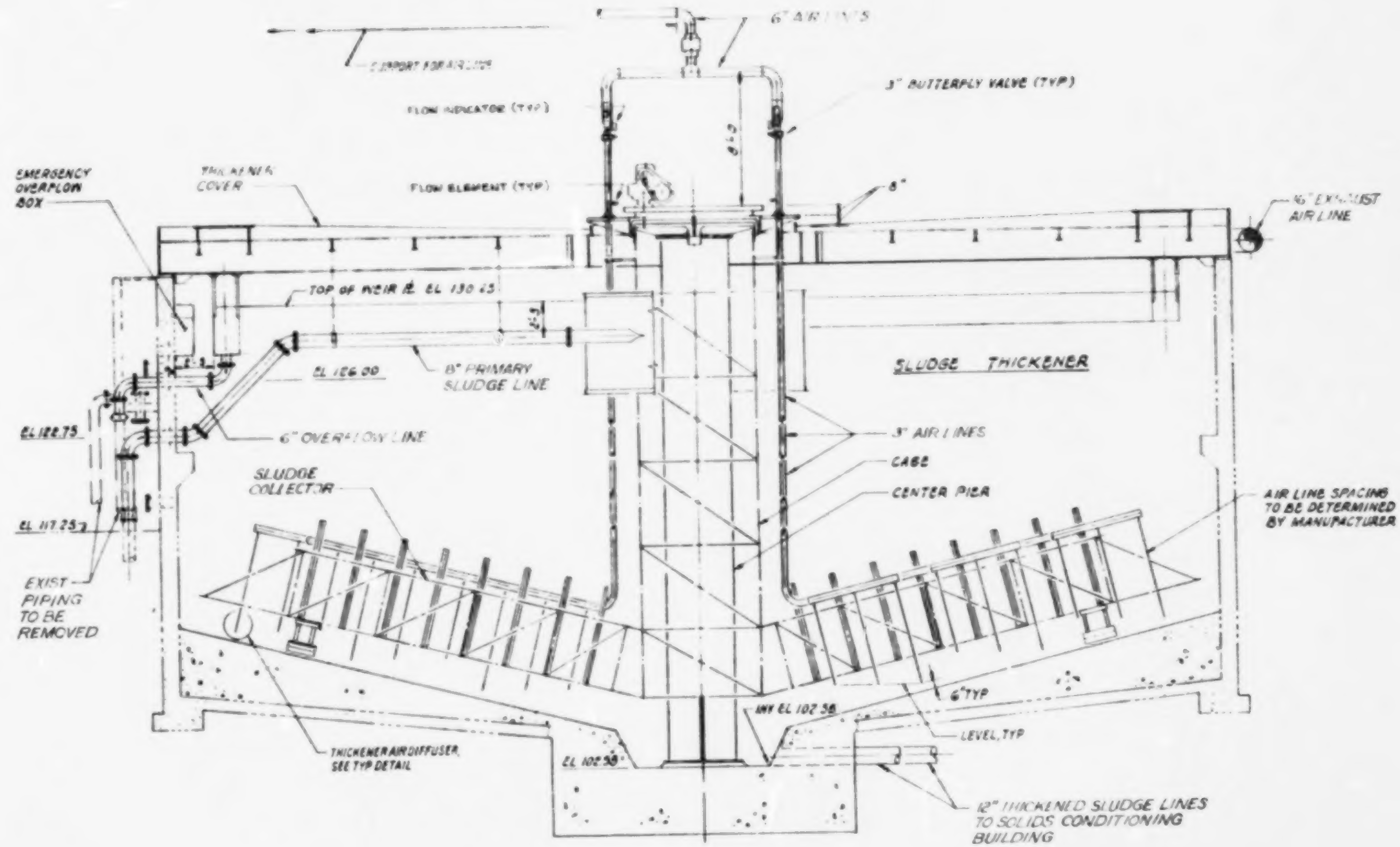

6" AIR LINES
SUPPORT FOR AIR LINE
3" BUTTERFLY VALVE (TYP)
FLOW INDICATOR (TYP)
FLOW ELEMENT (TYP)
6'-9
8"
EMERGENCY OVERFLOW BOX
THICKENER COVER
16" EXHAUST AIR LINE
TOP OF WEIR ℄ EL 130.65
6'-3
EL 126.00
8" PRIMARY SLUDGE LINE
SLUDGE THICKENER
EL 122.75
6" OVERFLOW LINE
3" AIR LINES
CAGE
CENTER PIER
SLUDGE COLLECTOR
AIR LINE SPACING TO BE DETERMINED BY MANUFACTURER
EL 117.25
EXIST PIPING TO BE REMOVED
6" TYP
INV EL 102.58
LEVEL, TYP
THICKENER AIR DIFFUSER, SEE TYP DETAIL
EL 102.58
12" THICKENED SLUDGE LINES TO SOLIDS CONDITIONING BUILDING

Figure 7-4 Gravity sludge thickener at the CCCSD water reclamation plant

the incorporation of fine bubbles into the centrate, resulting in some foam flotation. This phenomenon has been used at Blue Plains[9] to accomplish flotation thickening, as is discussed in this section under Flotation Thickening.

Thickening data obtained to date have resulted in wide variations in terms of design recommendations. Therefore, development of firm design criteria will have to await further investigation.

Flotation Thickening

Thickening of sludge by dissolved air flotation has seen wide acceptance in recent years, particularly in waste activated sludge applications. To separate solids from water by flotation, gas bubbles are formed by dissolving air into the water at a pressure of approximately 2.8 kg/sq cm (40 psig). The air charged stream is then mixed with the sludge where the pressure is released forming fine air bubbles which adhere to the solid particles. Once introduced into the tank, the lowered specific gravity of the solid particles causes them to rise to the surface. As the solids accumulate, a blanket of sludge is formed. An overhead skimmer removes the top of the sludge blanket, where the high solids concentration occurs, and discharges it to a sludge hopper. The relatively clear underflow moves out of the separation zone under a submerged baffle and flows over the effluent weir. Fig. 7-5 shows a schematic diagram of the air flotation process.[12] The pressurized flow source may be recycled thickener underflow, plant effluent or some other process flow.

When centrifugal equipment is used for separation of calcium carbonate from other waste solids (see Wet Classification in this section), the high speed centrifuge operation tends to aerate the sludge and to create fine bubbles in the centrate. These bubbles behave as air bubbles would in a conventional air flotation system when the centrate enters a quiescent tank. Bennett[9] has used this effect to accomplish thickening of the centrate solids without a supplementary air dissolution step. Centrate at 2-3 percent total solids, has been thickened by this procedure to 4.7 to 7.3 percent total solids. Bennett cautioned, however, that the transfer of the centrate to the thickening tank must be immediate to prevent bubble release from the sludge. To insure consistent operation, it is desirable to make provisions for standard air dissolution equipment.

The application of conventional air flotation equipment to thicken lime sludges must be approached with caution. The introduction of carbon dioxide from the pressurized air may cause scaling of equipment with the accompanying maintenance problems. Purified oxygen or nitrogen might prove a better gas source than ambient air for dissolved air flotation in this application, since they contain a negligible quantity of carbon dioxide.

Specific design criteria for flotation thickening of lime sludges have not been published to date.

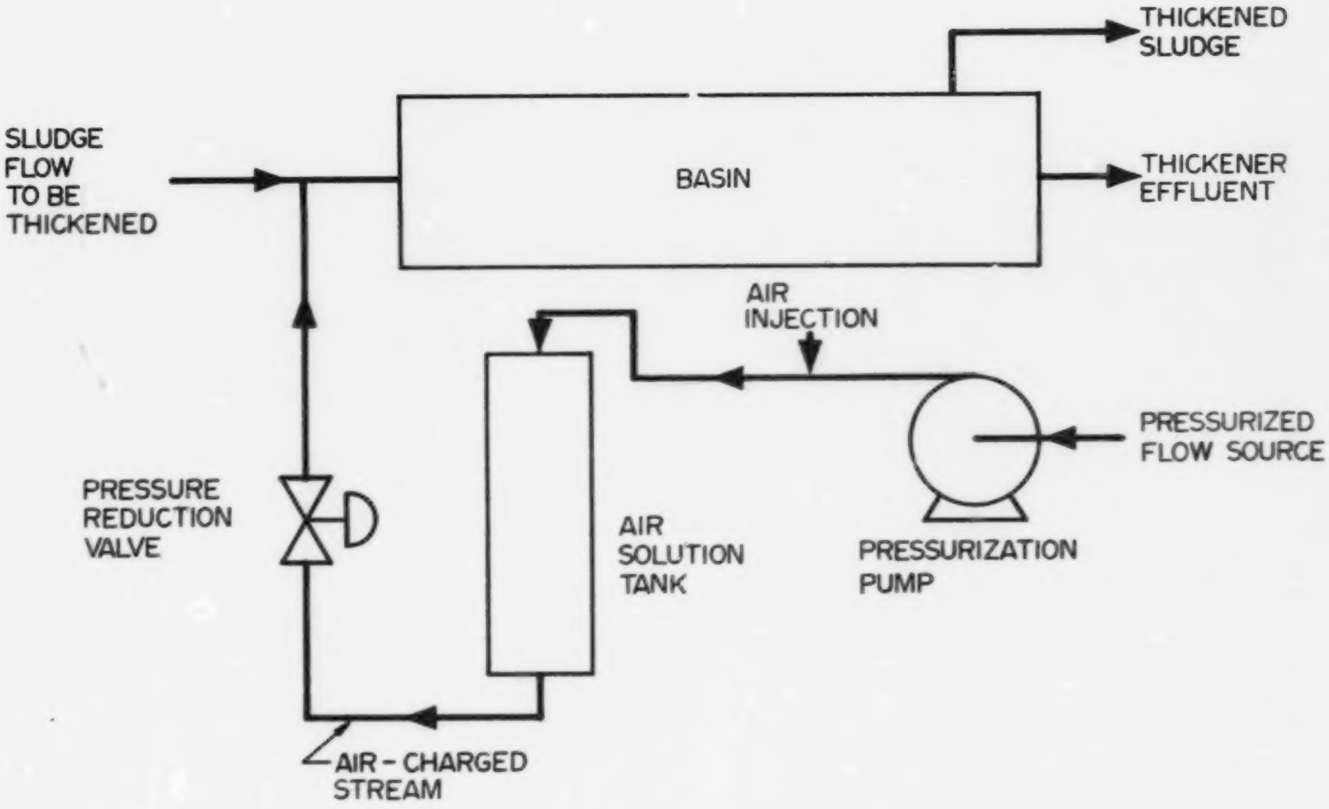

THICKENED
SLUDGE
SLUDGE
FLOW
TO BE
THICKENED
BASIN
THICKENER
EFFLUENT
AIR
INJECTION
PRESSURIZED
FLOW SOURCE
PRESSURE
REDUCTION
VALVE
AIR
SOLUTION
TANK
PRESSURIZATION
PUMP
AIR - CHARGED
STREAM

Figure 7-5 Schematic diagram of the dissolved air flotation process

SLUDGE DEWATERING

The main purpose of mechanical dewatering is to minimize the moisture content of the sludge. When oriented towards incineration, a more specific purpose is to increase the volatile content per pound of wet sludge. Approximately 450 kg-cal (1800 Btu) are required to evaporate a pound of water (at an off-gas temperature of 700 F); therefore, excessive moisture increases the thermal load on the incineration process and the amount of auxiliary fuel required. The influence of moisture content on the cost of sludge incineration is shown in Figs. 7-6 and 7-7 for primary sludge.[2]

Two methods are commonly used in the United States for sludge dewatering - vacuum filtration and centrifugation. A third method, utilizing filter presses, enjoyed limited use in the past,[10] although in recent years there has been renewed interest in pressure filtration for dewatering the more difficult sludges. Pressure filtration of sludge has been practiced in Europe for many years.

The methods employed for sludge dewatering have a marked impact on the solids processing design, when the objective is recovery of lime from sludges. When vacuum or pressure filtration is used to dewater the primary-generated sludge, all of the sludge is captured in a single dewatering stage. Therefore, all of the sludge must be recalcined in a Plural Purpose Furnace (Fig. 7-8). Inerts (constituents other than calcium carbonate or calcium oxide) must be controlled from building up through recycling after several passes; therefore, blowdown of a portion of the recalcined product is mandatory with consequential loss of a portion of the reclaimed lime.[3] Dry classification, a process described in detail in Section VIII, allows this ash blowdown to be somewhat more efficient in terms of rejecting silica inerts.

When centrifugation is employed, it is possible to classify the calcium carbonate from most of the magnesium, phosphorus, and iron compounds as well as from the organics. A high calcium carbonate cake is produced which can be recalcined (Fig. 7-9) to produce reclaimed lime. Dry classification can be effectively employed in this flowsheet to blow down silica. The centrate from the wet classification step containing the waste solids can be disposed of by a number of procedures. One alternate, shown in Fig. 7-9, is to use another centrifuge to separate the waste solids and use incineration to produce an ash residue for final disposal. Another alternative would be to employ lime stabilization of the solids prior to dewatering, followed by direct disposal of the cake as land fill. Alternately, digestion of the centrifuge centrate could be used before final disposal.[3]

Centrifugation

Centrifuges have long been used for sludge dewatering, although at a limited scale, due mostly to their early design and construction deficiencies.[10] However, the development of the present efficient machines has led to the wide acceptance of centrifuge equipment for mechanical dewatering applications. The theory of centrifugal separation has been presented in References 10 and 13.

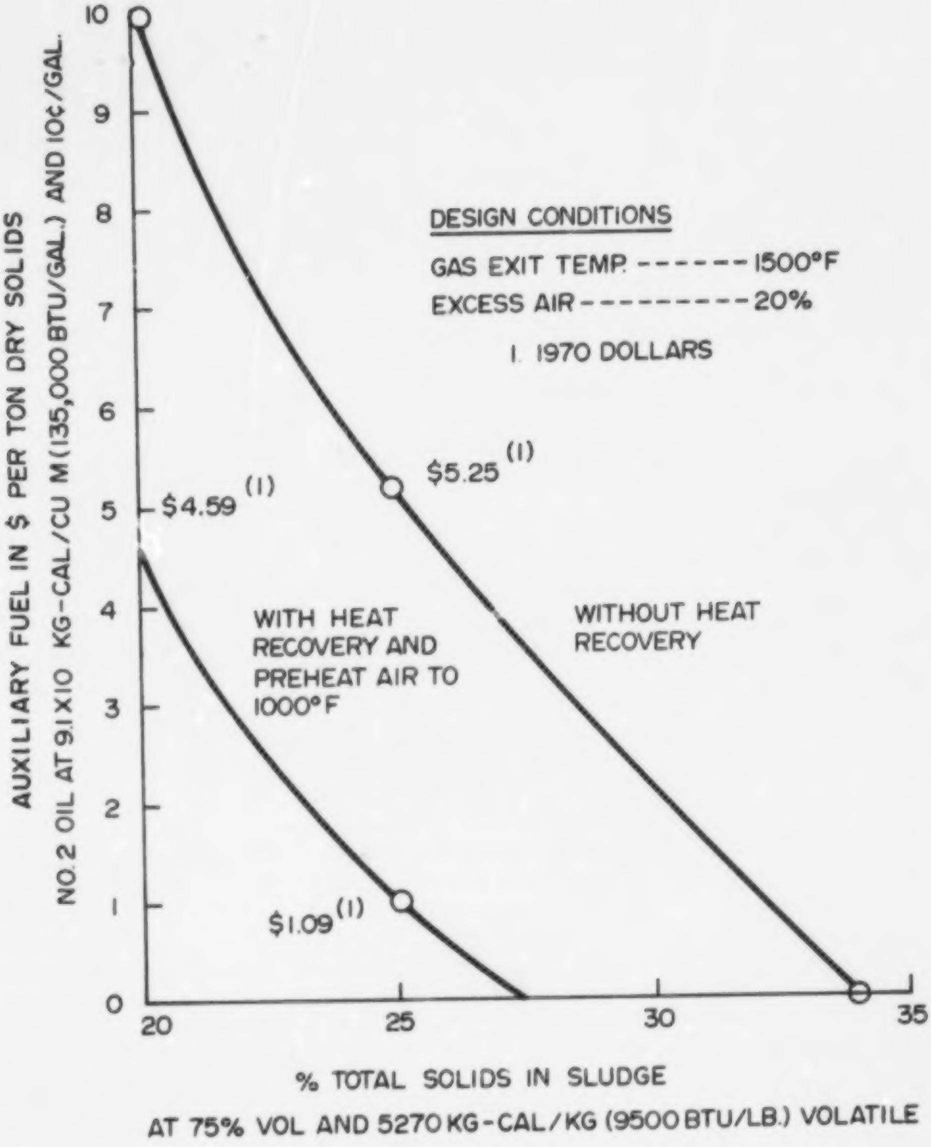


Figure 7-6 Effect of moisture content on the cost of sludge combustion

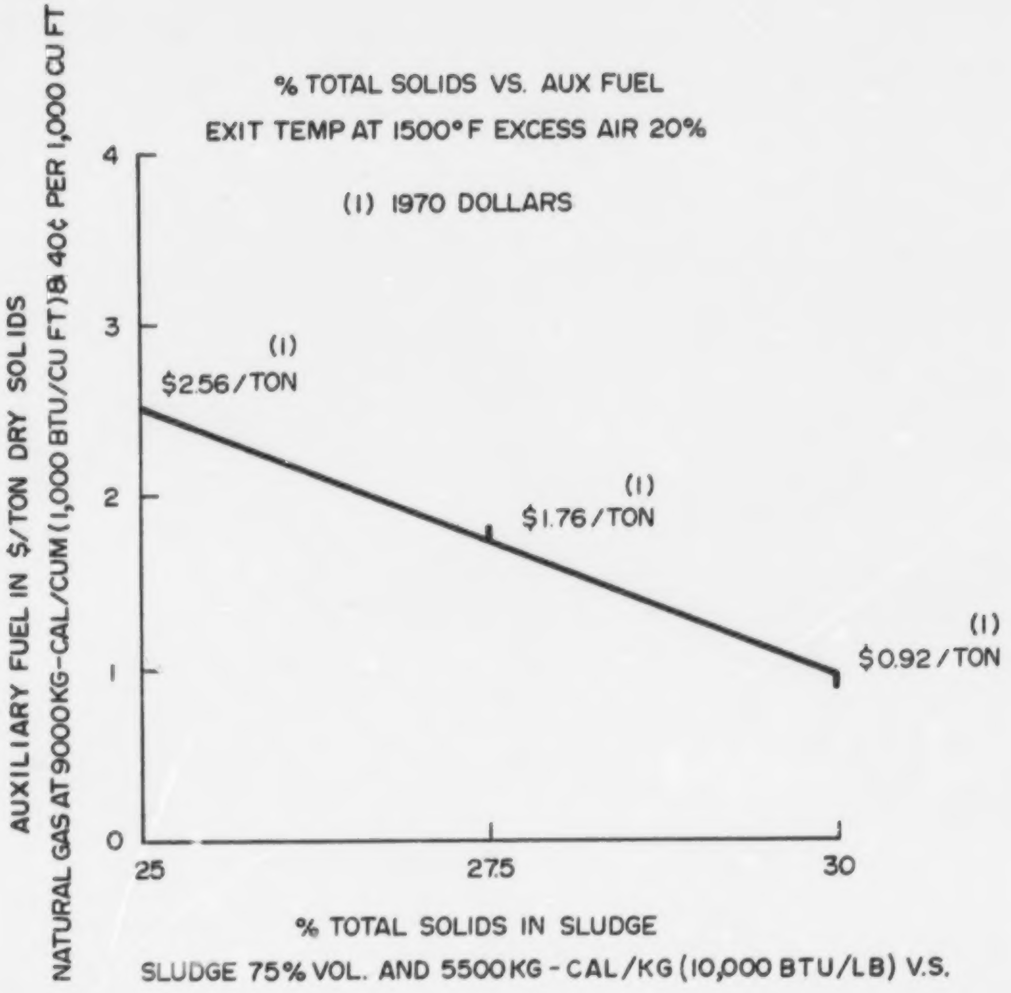


Figure 7-7 Effect of moisture content on the cost of sludge combustion

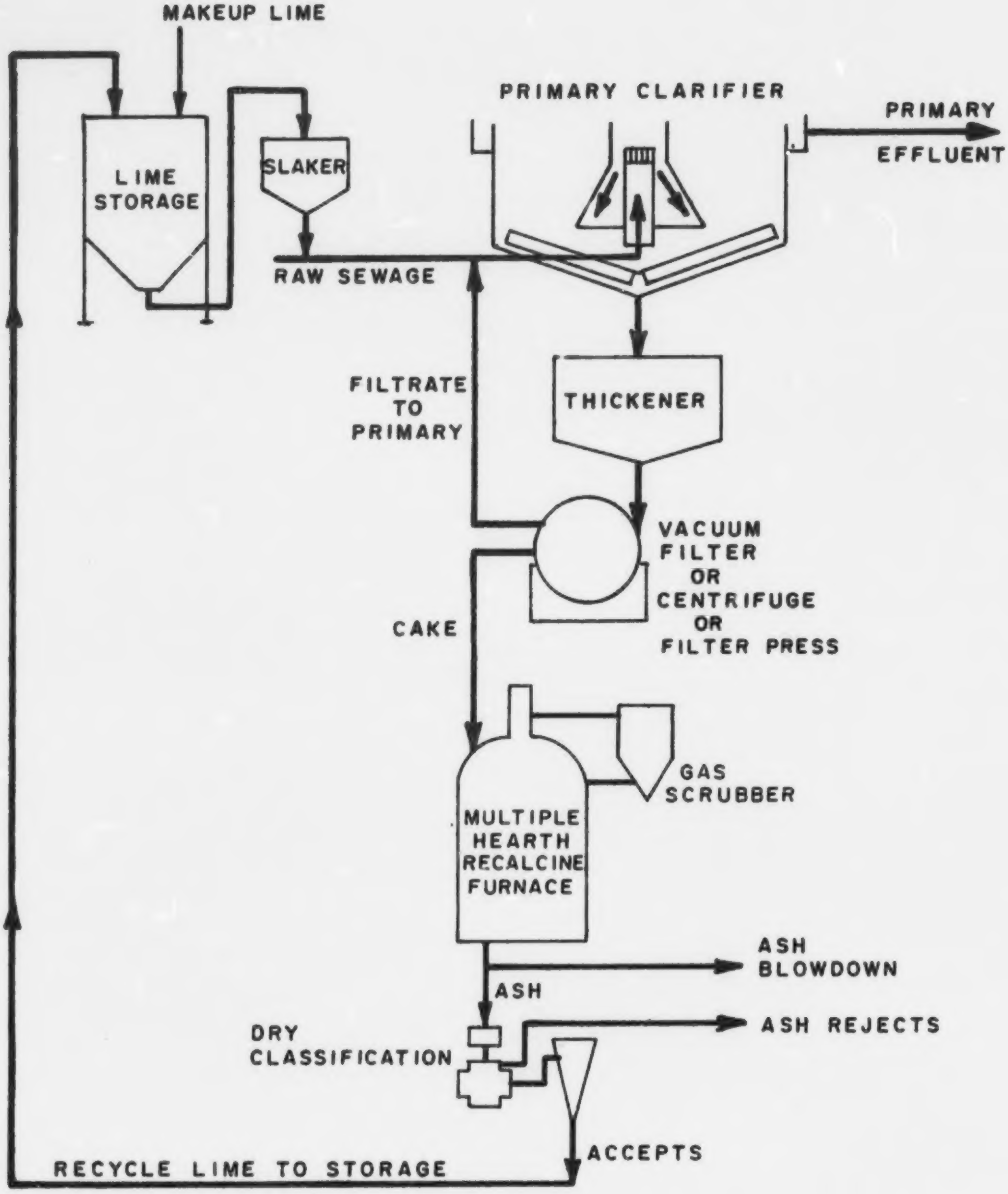

MAKEUP LIME
PRIMARY CLARIFIER
PRIMARY EFFLUENT
LIME STORAGE
SLAKER
RAW SEWAGE
FILTRATE TO PRIMARY
THICKENER
VACUUM FILTER OR CENTRIFUGE OR FILTER PRESS
CAKE
GAS SCRUBBER
MULTIPLE HEARTH RECALCINE FURNACE
ASH BLOWDOWN
ASH
DRY CLASSIFICATION
ASH REJECTS
ACCEPTS
RECYCLE LIME TO STORAGE

Figure 7-8 Conventional Plural Purpose Furnace flow sheet

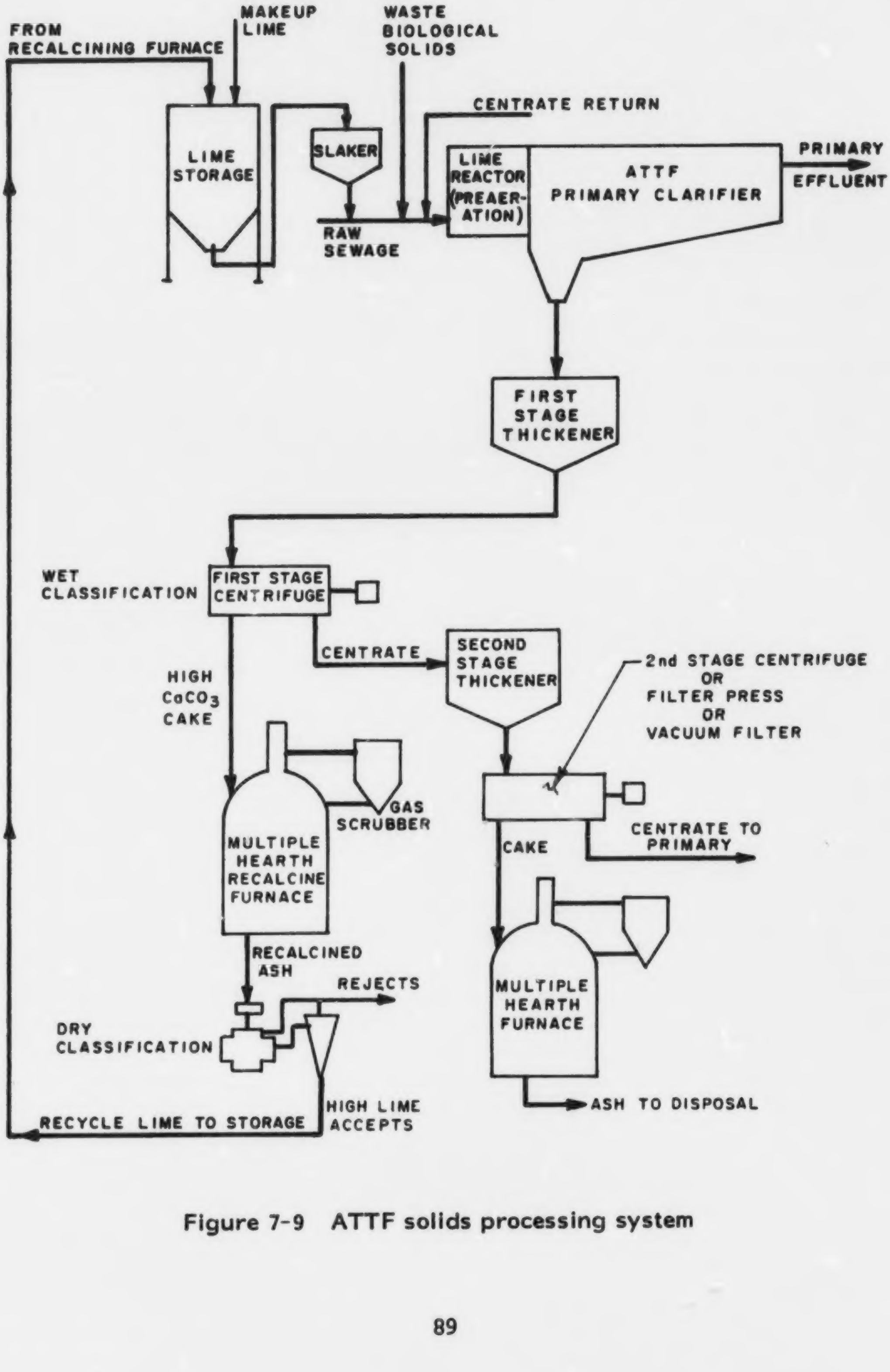

FROM
RECALCINING FURNACE
MAKEUP
LIME
WASTE
BIOLOGICAL
SOLIDS
CENTRATE RETURN
LIME
STORAGE
SLAKER
LIME
REACTOR
(PREAER-
ATION)
ATTF
PRIMARY CLARIFIER
PRIMARY
EFFLUENT
RAW
SEWAGE
FIRST
STAGE
THICKENER
WET
CLASSIFICATION
FIRST STAGE
CENTRIFUGE
CENTRATE
SECOND
STAGE
THICKENER
2nd STAGE CENTRIFUGE
OR
FILTER PRESS
OR
VACUUM FILTER
HIGH
$CaCO_3$
CAKE
GAS
SCRUBBER
MULTIPLE
HEARTH
RECALCINE
FURNACE
CENTRATE TO
PRIMARY
CAKE
RECALCINED
ASH
REJECTS
DRY
CLASSIFICATION
MULTIPLE
HEARTH
FURNACE
ASH TO DISPOSAL
HIGH LIME
ACCEPTS
RECYCLE LIME TO STORAGE

Figure 7-9 ATTF solids processing system

Three general types of centrifuges are available today - basket, disc, and solid bowl. However, only the last type is capable of producing both a dry sludge cake and a well clarified centrate in a single step.

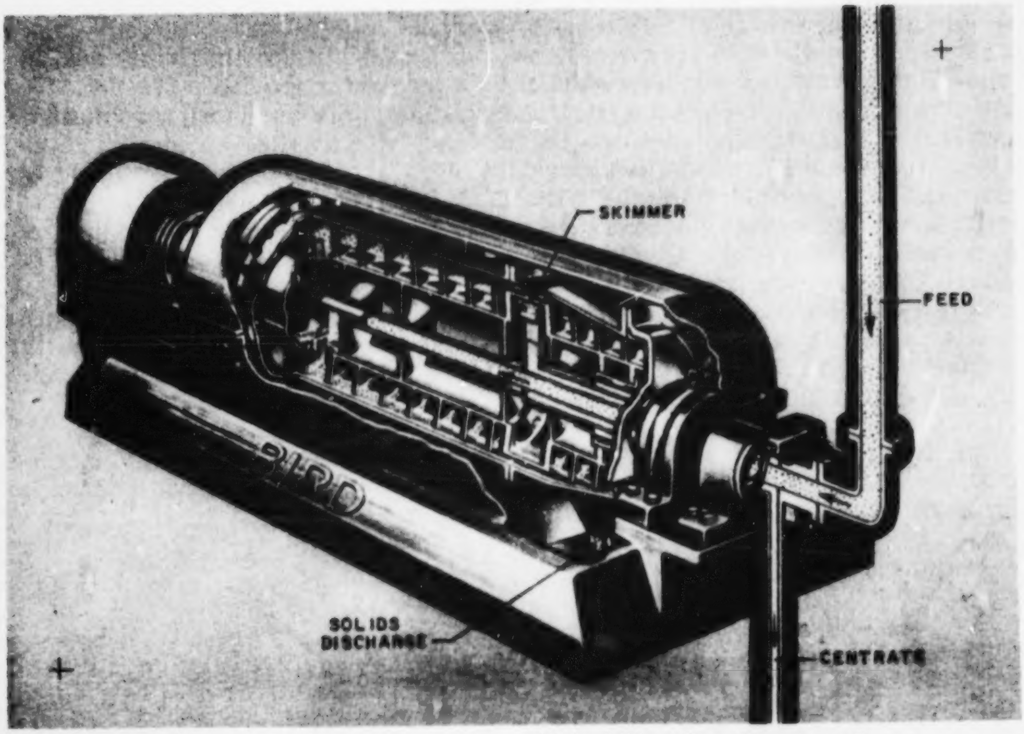
The main elements of a solid bowl, scroll type centrifuge are the rotating bowl and the conveyor mechanism. The solids, under the effect of the separating force ("G" force) settle in the cylindrical-conical bowl, and are then picked up by the screw conveyor which carries the settled solids to the discharge ports.

Solid bowl centrifuges used in sludge dewatering are available in two basic flow configurations - concurrent and counter-current. In the concurrent design, the feed is introduced at one end and the liquid and solids travel together toward the outlet ports. In the counter-current type, the feed is introduced near the conical portion of the bowl (the dewatering beach). The solids are moved in one direction while the centrate is discharged in the opposite direction. Fig. 7-10 shows both types of centrifuges.

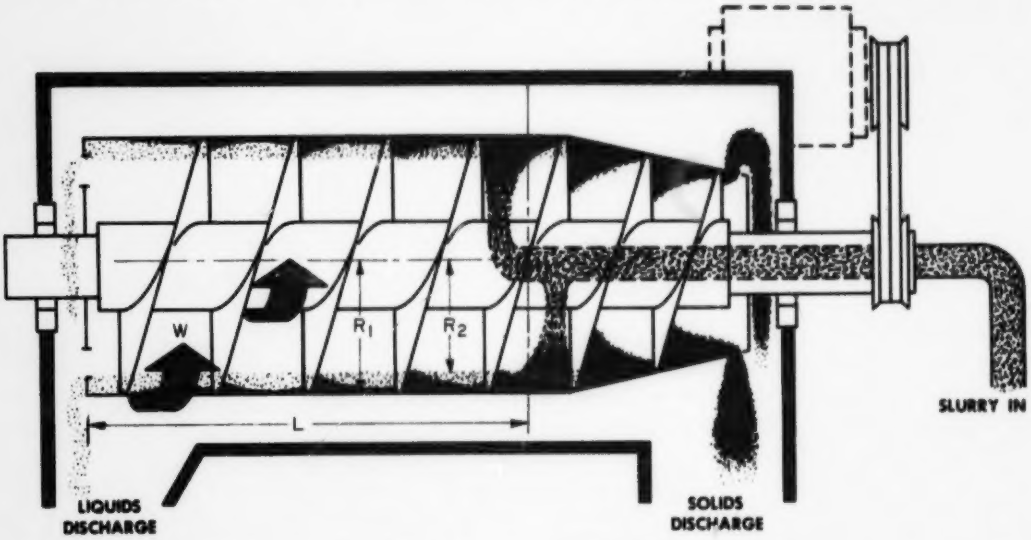
Solid bowl centrifuges can be manufactured of various alloys to provide protection under abrasive or corrosive operating conditions. Table 7-1 lists materials of construction used by a major manufacturer of centrifuge equipment. Where an abrasion problem is more likely to occur, such as in the feed zone and conveyor flights, hard surfacing techniques are often used to provide abrasion-resistant materials.

Table 7-1. SOME BASIC MATERIALS OF CONSTRUCTION USED IN SHARPLES CENTRIFUGES

METALS	ABRASION RESISTANT MATERIALS	CORROSION RESISTANT COATINGS
Steel, Carbon & Alloy	Tungsten Carbide (Solid)	Hard Rubber
Stainless	Tungsten Carbide (Plasma Fused)	Neoprene
304, 304L, 316, 316L	Tungsten Carbide Composites	Kynar
317L, 329, 17-4PH, 431	WC & Steel Matrix	TFE
(Misc PH Grades)	WC & Hastelloy Matrix	Penton
Carpenter 20-Cb 3	WC & Ni, Dr, B, Matrix	Tin, Cadmium, Zinc
Titanium, C. P. Grades	WC & Co, Cr, W Matrix	Nickel (Electroless)
Ti (6 Al-4V,), Ti (0.2% Pd)	Formaflex Coatings	Chromium
Hastelloy B; C-276	Ceramics (Solid)	Multiple Paint Systems
Wiscalloy B, C (Low Carbon)	Ceramics (Plasma & Flame Sprayed)	Epoxy-Phenolic
Monel 400, K-500	Hard Chromium & Armaloy	Urethane, Vinyl
Incaloy 800, 825	Cobalt-Chrome-Tungsten	Alkyd, Plastisol
Nickel 200	(Stellite-Stoody)	Organic Zinc
	Nickel-Chrome-Boron	
	(Colmonoy-Coast)	


SKIMMER
FEED
BIRD
SOLIDS DISCHARGE
CENTRATE

Concurrent flow centrifuge (courtesy of Bird Machine Company)


W
R_1
R_2
L
SLURRY IN
LIQUIDS DISCHARGE
SOLIDS DISCHARGE

-Counter-current flow centrifuge (courtesy of Sharples-Stokes, Division of Pennwalt Corporation)

Figure 7-10 Solid-bowl conveyor centrifuges

Centrifuges are normally designed for horizontal installation, although one manufacturer, Sharples, offers a line of vertical units. Among the advantages attributed to the vertical centrifuge, when compared to the horizontal design, are smaller floor space requirements and higher unit capacity. The latter feature is particularly advantageous in large installations where the required number of horizontal machines can be replaced by a smaller number of vertical units. This reduction of equipment would often compensate for the higher initial cost of the vertical centrifuges. At the CCCSD water reclamation plant, the capital cost of providing four vertical machines to wet classify 110,000 kg of dry solids (DS) per day (242,000 lb/day DS) and to clarify 40,800 kg/day (90,000 lb/day) DS (wet classification will be described later in this section) was 7.5 percent lower than the alternative to supply six horizontal machines to handle the same sludge quantities. Each alternative included the cost of the auxiliary equipment normally required for centrifuge operation. Fig. 7-11 shows the vertical centrifuge layout at the CCCSD plant.[11]

Sludge dewatering by centrifugation is affected by both process and machine variables. The Water Pollution Control Federation (WPCF) manual on sludge dewatering practices lists the following:

> "Process Variables:
>
> (a) sludge feed rate,
> (b) sludge solids characteristics,
> (c) sludge consistency,
> (d) sludge temperature, and
> (e) chemical addition."
>
> "Machine Variables:
>
> (a) bowl design;
>   i L/D ratio,
>   ii bowl angle,
>   iii flow pattern
> (b) bowl speed,
> (c) pool volume,
> (d) conveyor design, and
> (e) relative conveyor speed."

The effects of some of these variables will be covered in detail under Wet Classification. The best way to evaluate all of the variables listed above is through pilot plant testing. Test centrifuges are available from several equipment manufacturers, which use a scale-up factor, Σ, to predict results at full scale operation.[14]

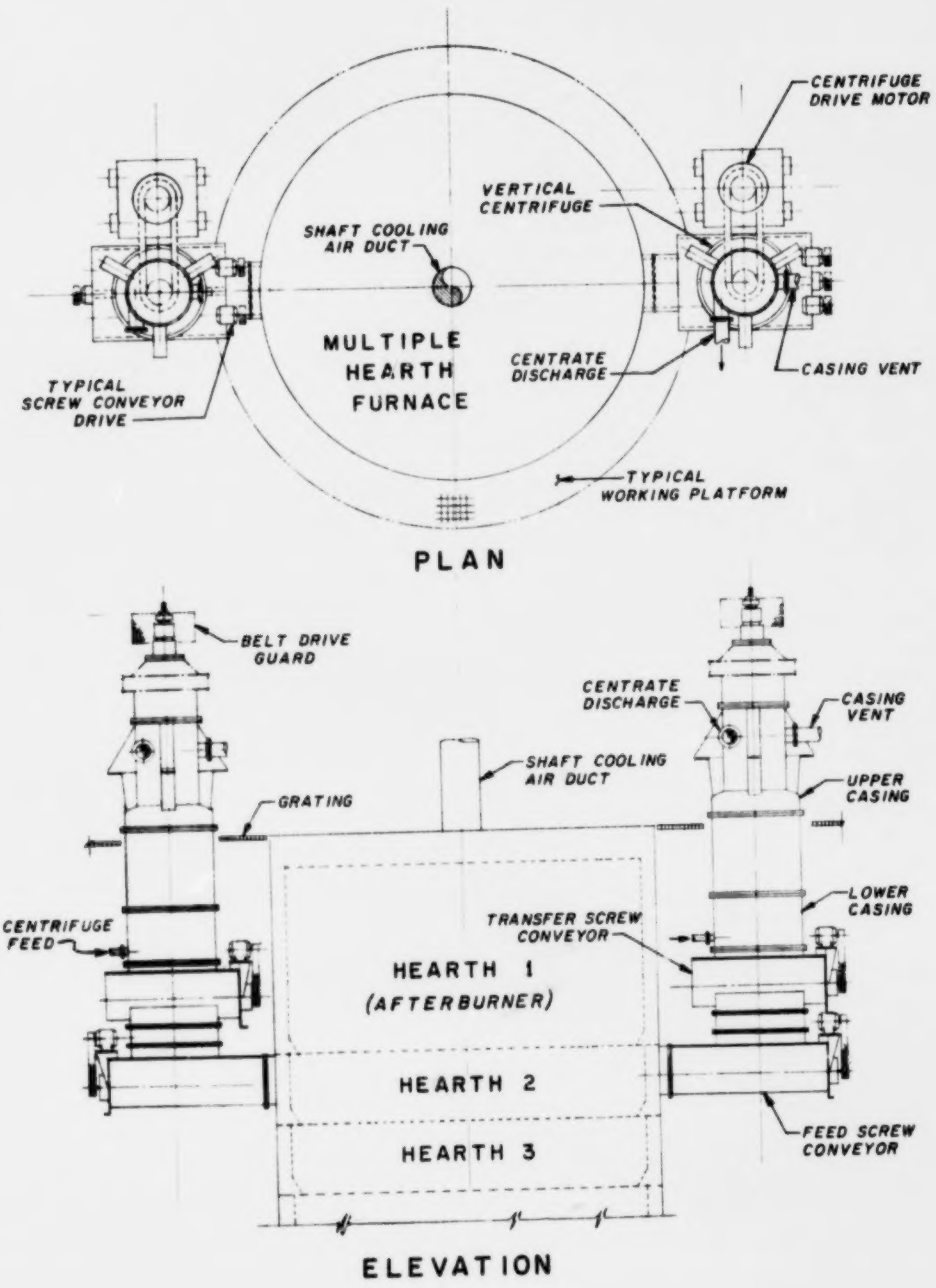

CENTRIFUGE DRIVE MOTOR
VERTICAL CENTRIFUGE
SHAFT COOLING AIR DUCT
MULTIPLE HEARTH FURNACE
CENTRATE DISCHARGE
CASING VENT
TYPICAL SCREW CONVEYOR DRIVE
TYPICAL WORKING PLATFORM
PLAN
BELT DRIVE GUARD
CENTRATE DISCHARGE
CASING VENT
SHAFT COOLING AIR DUCT
GRATING
UPPER CASING
LOWER CASING
TRANSFER SCREW CONVEYOR
CENTRIFUGE FEED
HEARTH 1 (AFTERBURNER)
HEARTH 2
HEARTH 3
FEED SCREW CONVEYOR
ELEVATION

Figure 7-11 Vertical centrifuge installation at the CCCSD water reclamation plant

Scaling Factors -

The equation for Σ is as follows:[14]

$$\Sigma = 2\pi \frac{Lw^2}{g}\left(\frac{3}{4}R_1^{\ 2} + \frac{1}{4}R_2^{\ 2}\right)$$

where: L = bowl length, cm
R_1 = radius of the liquid surface, cm
R_2 = radius of the inner wall of the bowl, cm
w = rate of rotation, rad/sec.

These terms have been represented in Fig. 7-10. The Σ factor represents the area, in sq cm, of a theoretical gravity sedimentation tank having equivalent clarification characteristics to the centrifuge. Thus, Σ can be used to relate capacities of different centrifuges, such as the filtering surface area which is used in sizing vacuum filters.

There is some controversy among centrifuge manufacturers concerning the appropriate bowl length to be employed in the Σ equation. Some manufacturers use the total bowl length, some include the portion of the dewatering beach that is wetted, and still others include only that portion of the beach between the liquid discharge and the mid-point of the feed ports. From a theoretical standpoint, the effective clarification length is most closely approximated by the latter definition for the counter-current design (see Fig. 7-10). At any rate, if machines of different manufacturers are to be compared, Σ must be calculated on the same basis for each. The calculation of the Σ factor is one of the essential steps in comparing equipment proposals of different manufacturers. However, it must be remembered that the value of Σ is only an index of clarification capacity for a given centrifuge. Machine speed, i.e., rpm or "G", also influences cake dryness and it is another important parameter in design and operation of centrifuges.

Sample calculations for Σ are shown below:

Manufacturer A
Model X

L = 86.4 cm
w = 251 rad/sec
R_1 = 30.5 cm
R_2 = 22.8 cm
g = 980 cm/sec^2

$$\Sigma = 2(86.4)\,\frac{(251)^2}{980}\left[\frac{3}{4}(30.5)^2 + \frac{1}{4}(22.8)^2\right]$$

$$\Sigma = 2.9 \times 10^7\ \text{cm}^2$$

Manufacturer B
Model Y

L = 98.7 cm
w = 262 rad/sec
R_1 = 31.8 cm
R_2 = 26.4 cm
g = 980 cm/sec^2

$$\Sigma = 2(98.7)\,\frac{(262)^2}{980}\left[\frac{3}{4}(31.8)^2 + \frac{1}{4}(26.4)^2\right]$$

$$\Sigma = 4.0 \times 10^7\ \text{cm}^2$$

From the above calculation, it would be expected that it would take four of Manufacturer A's machines to do the job that three of Manufacturer B's machines would do.

Wet Classification

The problem in recovering lime from raw sewage sludge is that many constituents are precipitated with the sludge besides calcium carbonate. As explained in Section VI, organics, phosphorus, magnesium, iron, and other constituents are coprecipitated with calcium carbonate. These constituents, if left with the calcium carbonate during recalcining, are returned to the process. Eventually, these "inerts" build up to such a magnitude that the solids processing facilities are overwhelmed. This problem has been the major reason that recovery of lime added in the primary sedimentation tanks has not been practiced.[15] The problem of lime recovery has also been a deterrent to the use of lime in raw sewage coagulation.

Sludge solids vary greatly both in size and density and as a result, they settle at widely different rates. The process whereby the sludge constituents are separated into various categories based on this spread in settling rates is called wet classification. Centrifugal action magnifies the difference in settling of solids particles; therefore, centrifuges are particularly suitable for wet separation. The ability of centrifuges to classify particles on the basis of both size and density has been used in industrial applications for many years.[16] Wet classification has been used for over three decades to control inerts buildup in water softening plants practicing lime reclamation.[17,18,19] Classification data from three studies where Bird centrifuges were employed are shown in Table 7-2. Except for anamolous behavior with silica, good rejection of all components was obtained, while retaining silica. The procedure for calculation of the recoveries has been described previously.[3]

Table 7-2. CLASSIFICATION DATA FOR WATER TREATMENT PLANT SLUDGES

Plant	Recovery of stated constituent, percent									
	Wright Aeronautical Corp., Cincinnati, Ohio[a]			Columbia Steel Corp., Provo, Utah[a]		Marshalltown, Iowa[b]				Findlay Ohio[c]
Constituent	Run 1	Run 2	Run 3	Run 1	Run 2	Control	Cycle 1	Cycle 2	Cycle 3	-
Total Solids	74	81	96	92	85	80	75	75	77	73
Calcium	84	88	100	96	90	89	98	95	92	77
Magnesium	51	57	36	3	3	16	20	9	20	40
Iron	43	11	53	51	47	62	58	66	70	-
Aluminum	17	40	<1	50	58	-	-	-	-	-
Silica	-	-	38	92	-	-	-	-	-	-

[a] Reference 17
[b] Reference 18
[c] Reference 19

In the case of lime sludges, the purpose of wet classification is to maximize recovery of calcium carbonate in the centrifuged cake while rejecting the other components to as great an extent as possible. The calcium carbonate crystals settle more rapidly than the other solids. Consequently, a partial recovery of the total solids with a centrifuge concentrates the calcium carbonate along with the heavy inert solids in the cake.

Classification Efficiency - Classification efficiency of a centrifuge is expressed in terms of the percentage of the particular constituent in the feed that is recovered in the cake. Good classification efficiency is achieved when calcium carbonate recovery is high and when recovery of the other constituents is low.

In pilot plant studies at the CCCSD's ATTF,[3,20] the recovery of each component was compared with the total solids recovery, to get an indication of the efficiency of component classification. The relationships derived from this analysis are shown in Fig. 7-12. From the figure, it can be observed that there is a fairly broad range in which fairly high calcium carbonate recovery is coupled with reasonable classification. For instance, at 50 percent total solids recovery, 70 percent of the calcium carbonate is recovered with less than 30 percent of the other major constituents, while at 70 percent total solids recovery, almost 90 percent of the calcium carbonate is recovered with less than 50 percent of the other major constituents, except the acid insoluble inerts. The one constituent without good classification characteristics is the acid insoluble inerts. Recoveries shown in Table 7-3 range from 41 to 100 percent recovery. Quite wide variation in recovery of these inerts was obtained, perhaps because of variations in composition of these inerts in the feed sludge. In subsequent work[21] where recalcined lime was recycled, the acid insoluble inerts were found to be comprised primarily of silica (80 to 90 percent).

Data obtained at the CCCSD's ATTF on classification during a representative period of lime reuse are shown in Table 7-4.[21] During this work, specific tests on the silica levels in the sludge allowed the determination of silica recovery at 85 percent. This means that there is essentially no rejection of silica; it is recovered at nearly the same level as calcium carbonate. A plot of the classification relationships determined during the ATTF test work on lime recycling is shown in Fig. 7-13. Classification for all constituents, except ferric hydroxide and silica, was similar to that experienced without lime recycle (Fig. 7-12). With silica, it was found that recovery increased from less than the calcium carbonate recovery prior to lime recycle to a level greater than the calcium carbonate recovery after lime recycle.[21] Apparently, the furnace operation altered the classification characteristics of the silica recycled to the process. Iron recoveries were consistently greater than experienced previously, even during the period prior to the actual implementation of lime recycle. It is felt that this was due to the addition of iron to the downstream nitrification system, so that iron precipitates entered the primary incorporated into the waste activated sludge, rather than as a supplemental coagulant as in previous work.

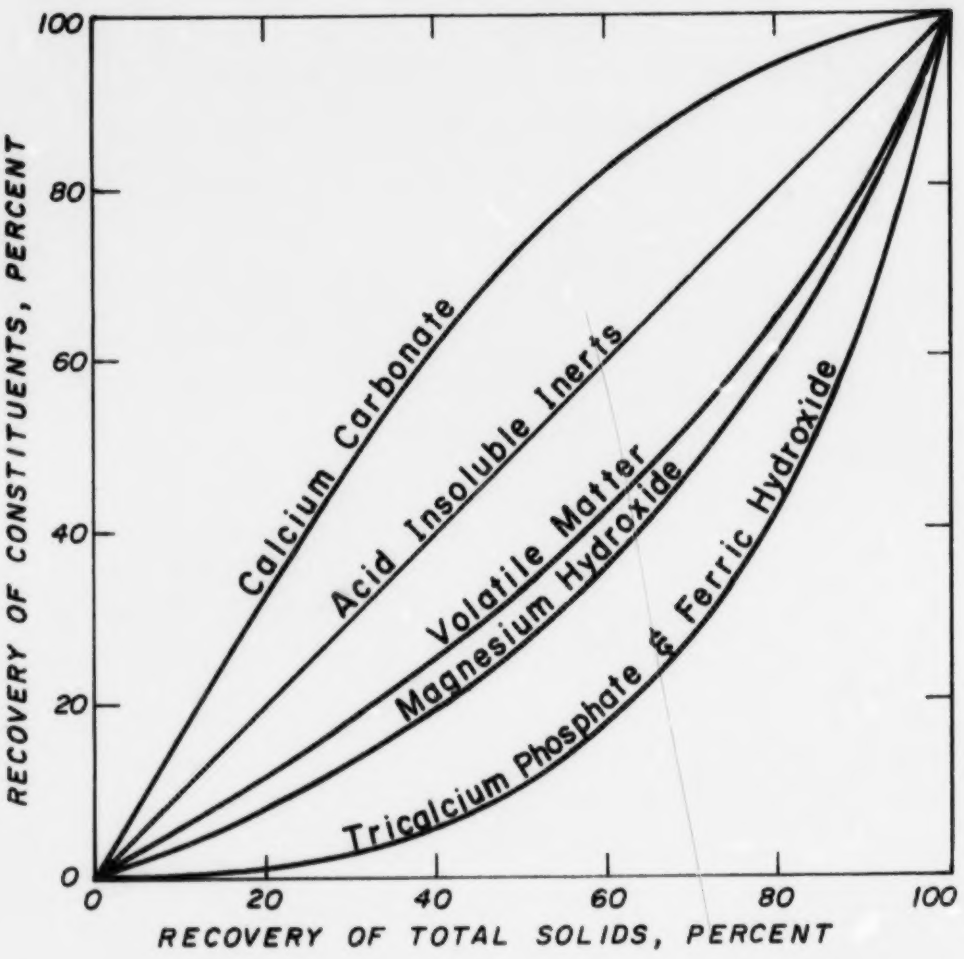


Figure 7-12 Summary of constituent recoveries during wet classification without lime recycle

Besides demonstrating the feasibility of wet classification of lime sludges, the data presented in Table 7-3 show the wide range in degree of classification attained. These variations are due primarily to differences in centrifuge operating conditions. The principal variables are feed rate, centrifugal force, and pond depth setting.

Table 7-3. RUN DATA FOR WET CLASSIFICATION

Process Parameters								Recoveries in Cake, percent						
Run	Machine	Centrifugal force per lb mass, g's	Conveyor speed, △RPM	Conveyor pitch, in.	Pond number	Feed rate, gpm[c]	Floccula-tion pH	Total solids	Calcium carbonate	Magnesium hydroxide	Tricalcium phosphate	Ferric hydroxide	Volatile matter	Acid Insoluble Inerts
2-7	Sharples P-600	2100	50	2	1	8	11.5	67	90	30	23		41	57
2-5						10		63	86	27	20		41	51
2-1					3	10		69	90	43	25		43	57
2-4						12		65	78	35	24		49	87
2-32		1050	35		1	9		66	84	66	18		59	44
2-12[a]		2100	16		3	3		86	~ 100	51	76		65	60
8-1	Sharples P-3000	2100	26	3	1	23	11.0	64	96	44	10		50	66
8-4						49		56	89	34	11		42	60
8-12					2	25		69	88	64	30		43	67
8-9						49		47	57	31	13		32	50
8-8					3	21		72	96	58	34		56	66
8-5						49		64	75	45	41		55	66
8-41		1500			1	19		61	85	36	11		42	76
8-40		1500				43		55	76	32	9		35	74
4-3-72	Sharples P-600	3050	65	1	1	10		62	87	30	23	31	38	56
4-134		2100	50			5	10.2	57	79	38	23	23	41	41
4-106						7		48	69	21	18	6	33	52
4-105						14		49	77	32	16	12	35	30
4-123[b]			9		4	4		97	~ 100	97	89	87	91	~ 100

[a] Three pounds of Allied Chemical colloid 726 polymer added per ton of dry solids in the feed.

[b] Two and a half pounds of ICI America Atlasep 2A2 polymer added per ton of dry solids in feed.

[c] One gpm = 0.0408 l/sec

Table 7-4. CENTRIFUGE PERFORMANCE SUMMARY-LIME SLUDGE RECYCLE PROJECT

Date	Total Solids Recovery Percent	Recoveries in Centrifuge Cake, Percent[a]						
		$CaCO_3$	Volatile Matter	$Ca_3(PO_4)_2$	$Mg(OH)_2$	$Fe(OH)_3$	SiO_2	Other[b]
7-27	62.9	87.4	42.8	18.0	7.5	62.9	66.2	(100)
29	61.8	82.1	38.5	21.8	28.9	54.0	75.8	61.8
31	60.4	82.7	40.4	17.8	41.8	48.3	-	84.6
8-2	57.7	78.8	35.7	21.5	30.3	43.2	99.6	69.2
4	53.4	77.9	32.0	19.7	25.6	53.4	82.3	(100)
6	55.2	78.3	33.2	23.4	25.6	55.2	94.0	47.3
8	56.6	76.8	35.9	21.4	36.3	51.9	84.1	75.5
10	53.0	84.7	29.0	19.5	18.7	53.0	90.0	63.7
Mean	57.6	81.0	35.9	20.4	26.8	52.7	84.6	75.3

[a] Operational pH in the primary was 11.0; the machine was the Sharples P3000 operating at 2100 G, a pond setting of 1, and an influent flow rate ranging from 2.2 to 2.5 l/sec (35.2 to 40.0 gpm)

[b] Acid insoluble inerts other than silica

Effect of Feed Rate - One of the most important parameters in the design of equipment is the feed rate and the effect of variations in feed rate. Fortunately, wide variation in feed rate can be tolerated for the purpose of constituent classification. Examination of the data in Table 7-3 reveals that for runs made under the same conditions, except for feed rate, there was only a slight deterioration in constituent classification with an increase in feed rate.

Effect of Centrifugal Force - Another important variable in centrifuge operation is the centrifugal force. Most of the runs were made at a centrifugal force per unit mass of 2,100 times the acceleration of gravity (G). However, a few runs were made at different G levels. Over the range of about 1,000 to 3,000 G, recovery of calcium carbonate increased only slightly with an increase in centrifugal force.

Effect of Pond Setting - The depth of the liquid layer in the centrifuge bowl would be expected to be an important variable. Increasing the depth of the liquid (increasing pond number) had an adverse effect on the separation of constituents. The best constituent separation was always attained at the lowest pond setting. For example, runs 8-4 and 8-5 (Table 7-3) held all process parameters constant except pond setting. The pond setting of 1 as compared to 3 gave a higher recovery of calcium carbonate and a greater rejection of all other components.

Effect of Lime Dosage, or pH - There is some indication that calcium carbonate is more easily classified from the other components at a high pH than at a low pH. Further, calcium carbonate recovery was better at a high pH than at a low pH. However, some of the other variables were also changed simultaneously with pH, and the pH effect could therefore not be firmly established. For example, runs made at pH of 10.2 and 11.5 were made with different machine conveyors, while runs made at pH 11.0 were made with the larger of the two machines. Also, the concentration of the various constituents in the sludge was substantially different at the various pH levels, and that also could account for the differences in degree of classification.

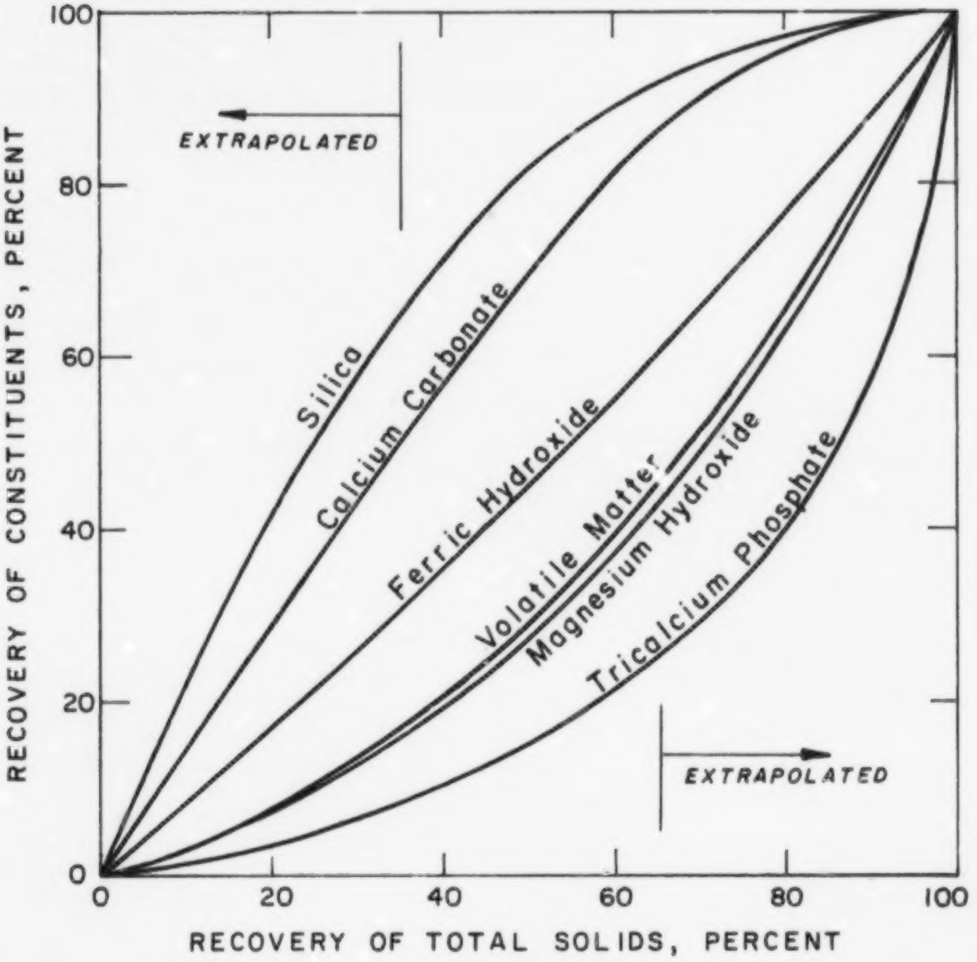


Figure 7-13 Summary of constituent recoveries during wet classification with lime recycle

Dewatering During Wet Classification -

Besides classifying the individual constituents of the solids, the dewatering of the recovered cake must also be considered. Factors which are important are the centrifuge operating conditions and the lime dosage or pH level used in the primary treatment from which the sludge is produced. As with the classification of solid constituents, the extent of dewatering is affected by several centrifuge operating variables. The effects of feed rate, centrifugal force and pond setting have been studied to determine their relative importance.

Effect of Feed Rate - As was noted in the discussion of constituent classification, feed rate can be varied over a wide range with only a minor effect on classification. Feed rate was also found to have little effect on total solids recovery at all pH levels. For instance at pH 11.0 (Fig. 7-14) total solids recovery at a pond setting of 1, decreased only from 63 to 54 percent when flows increased from 0.9 to 3.2 l/sec (15 to 50 gpm), more than a threefold range.

Effect of Centrifugal Force - For constituent classification, centrifugal force seemed to have a slight influence. For dewatering and solids recovery, however, the tests showed that centrifugal force is an important variable. Increasing the centrifugal force improved dewatering (Fig. 7-14 and 7-15). A centrifugal force of 2100 appears to be adequate for dewatering.

Effect of Pond Setting - The liquid depth (pond setting) had a substantial effect on cake dryness (Fig. 7-15). For dewatering, as in classification, the best results were obtained with as shallow a liquid depth as possible (pond setting No. 1).

Centrate Processing by Centrifugation -

One alternative for processing the centrate from the wet classification stage is to dewater the centrate in a second stage centrifuge and incinerate the cake. In addition to dewatering the rejected solids from wet classification, a high recovery of solids in the second stage is necessary to prevent a large return of solids to the primary treatment process. The solids to be captured in the second centrifuge stage are the slow-settling solids which were rejected in the first centrifuge stage. Different operating conditions must therefore be used in the second stage than in the first stage. Efficient capture requires the addition of a polymer and a high centrifugal force to improve the settling characteristics. Since it was found that with high recoveries the extent of classification among the constituents was small, the major concern is the dewatering and capture of the solids.

Effect of Conveyor Speed - Since the solids separated by centrifugal force are removed from the bowl with a conveyor, its speed relative to the bowl speed (Δ rpm) is one of the important operating variables. An example of the effect of conveyor speed is shown in Fig. 7-16. The polymer requirement to attain an 80 percent recovery of solids was reduced to about half by increasing the conveyor speed from 8 to 12 Δ rpm. However, the extent of dewatering was

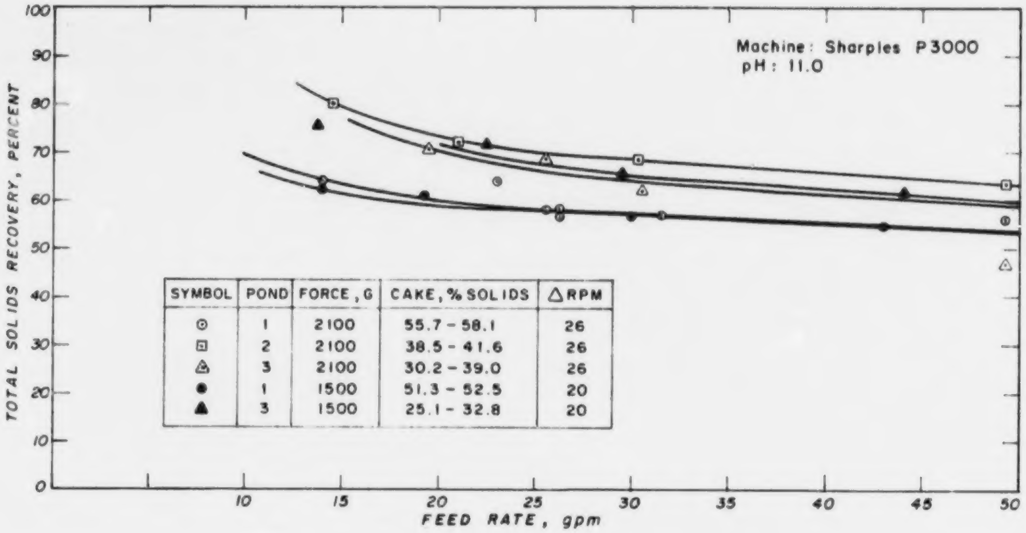


Figure 7-14 Effect of feed rate on solids recovery

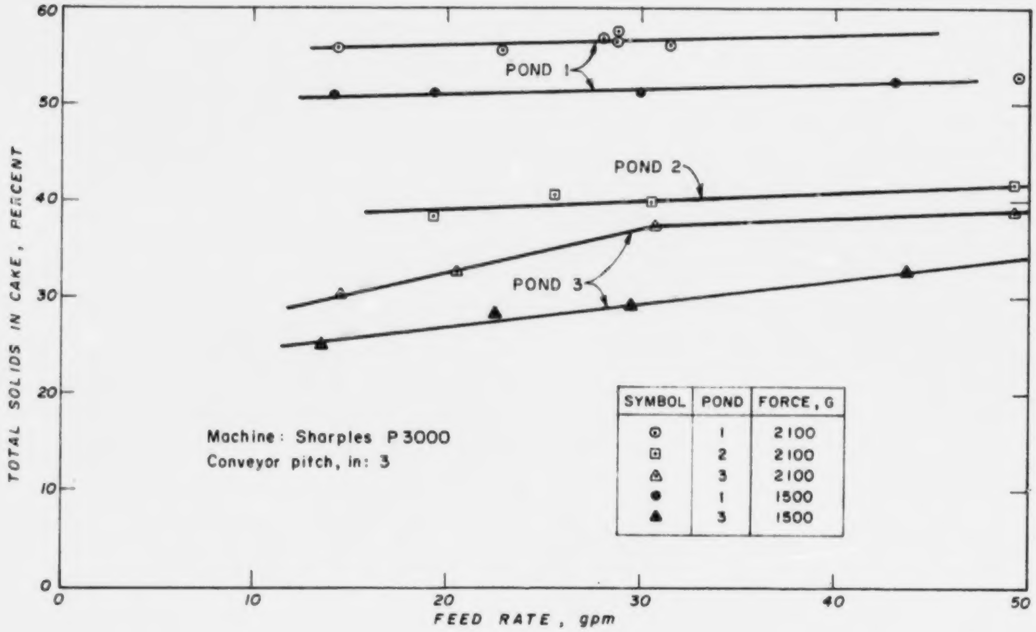
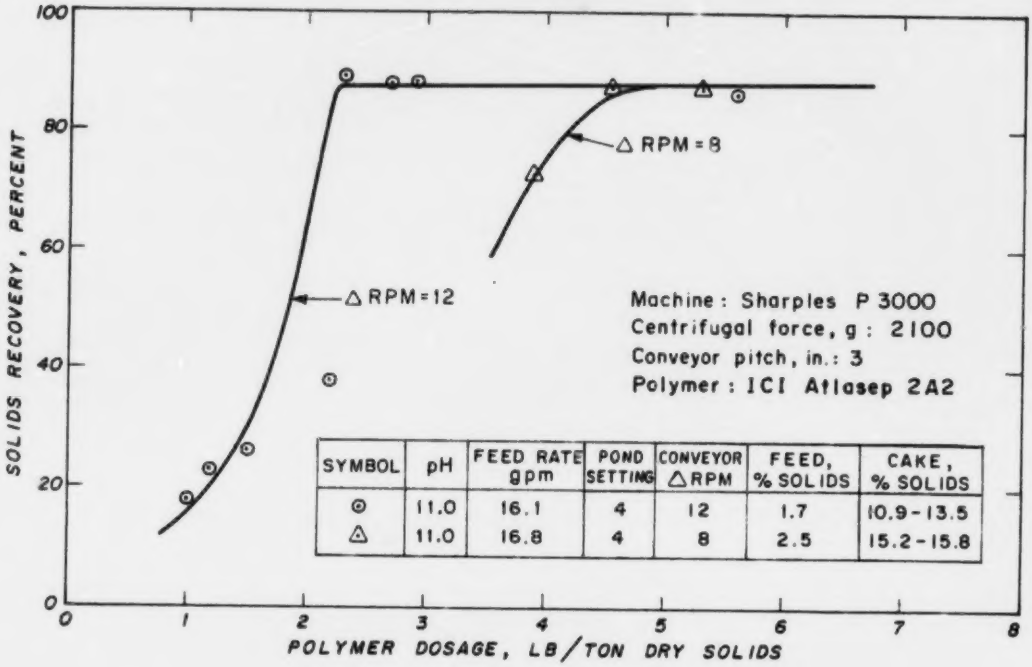


Figure 7-15 Effect of pond setting on dewatering at pH 11

reduced by the increased conveyor speed. Apparently there is an optimum conveyor speed that gives the best balance between polymer usage and extent of dewatering for a given feed and set of operating conditions.

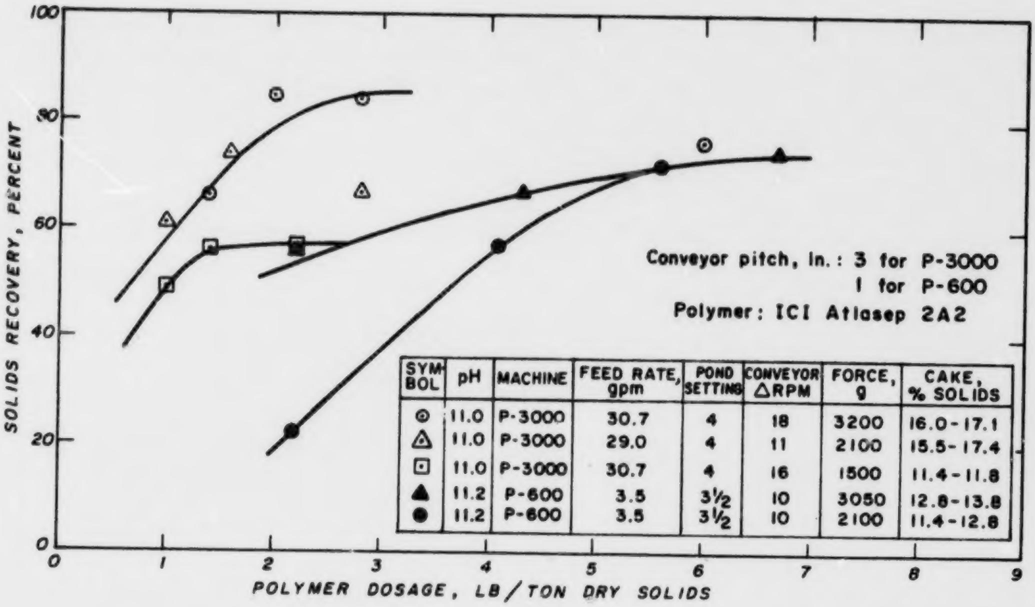


SYMBOL	pH	FEED RATE gpm	POND SETTING	CONVEYOR △RPM	FEED, % SOLIDS	CAKE, % SOLIDS
⊙	11.0	16.1	4	12	1.7	10.9 - 13.5
△	11.0	16.8	4	8	2.5	15.2 - 15.8

Figure 7-16 Effect of conveyor speed on polymer requirement

Effect of Pond Setting - Several factors are involved when the liquid depth is changed. Increasing the depth increases the liquid residence time, which should improve the separation. Offsetting to an extent the increased residence time is a reduced centrifugal force at the liquid surface because the surface is nearer the hub of the revolving bowl. Consequently, the average centrifugal force is reduced. Increasing pond depth also increases solids removal efficiency. As the depth is increased, the solids are more easily "lifted over" the beach of the bowl by the conveyor. For the second centrifuging stage it was found that increasing the liquid depth reduced the required polymer dosage to attain a given recovery, but also reduced the solids content of the cake.

Effect of Centrifugal Force - Recovery would normally be expected to improve with an increase in centrifugal force, with the only limitation being the equipment and operating cost relative to the improvement in degree of recovery. As shown in Fig. 7-17, solids recovery is improved as the centrifugal force is increased.



SYMBOL	pH	MACHINE	FEED RATE, gpm	POND SETTING	CONVEYOR △RPM	FORCE, g	CAKE, % SOLIDS
⊙	11.0	P-3000	30.7	4	18	3200	16.0-17.1
△	11.0	P-3000	29.0	4	11	2100	15.5-17.4
⊡	11.0	P-3000	30.7	4	16	1500	11.4-11.8
▲	11.2	P-600	3.5	3½	10	3050	12.8-13.8
●	11.2	P-600	3.5	3½	10	2100	11.4-12.8

Figure 7-17 Effect of centrifugal force on solids recovery

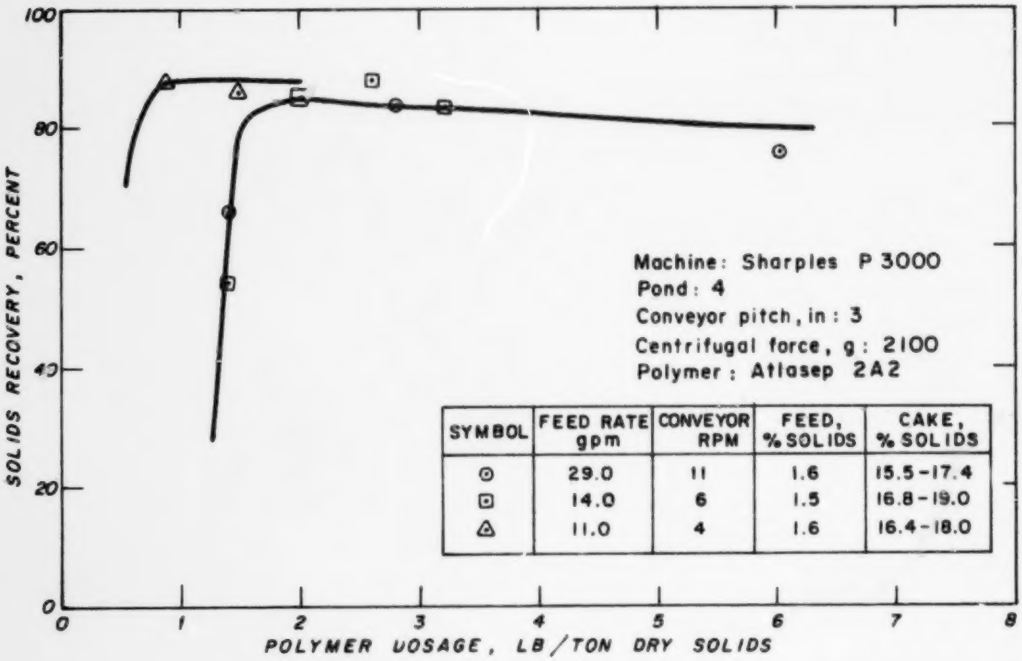
Effect of Feed Rate - In the centrifuge test runs shown in Fig. 7-18, the feed rate was varied from 0.9 to 1.8 l/sec (14 to 29 gpm) with no significant change in polymer requirement or percent of solids recovered. There was an apparent slight increase in cake water content at the higher feed rate. At the low feed rate of 0.7 l/sec (11 gpm), about a third of the maximum rate used, solids recovery was slightly better, and the polymer requirement was reduced. Fig. 7-18 shows that a wide range of feed rates can be used without changing the efficiency to any great extent, which will lend flexibility to prototype operation.

For the runs at different feed rates, the conveyor speed was also varied to maintain a relatively constant ratio of feed rate to conveyor speed. Since the concentration of solids in the feed was essentially constant, the amount of solids removed per conveyor revolution was also maintained constant, thereby essentially eliminating the effect of conveyor speed on cake dryness.

Effect of Flocculation pH - No relationship was found between flocculation pH and the polymer dose required to attain a given recovery level. However, significant differences occurred in the observed dewatering. A flocculation pH greater than 11.0 had a detrimental effect on second stage water content as shown in Table 7-5. This difference would have a significant impact on sludge incineration costs and would be a drawback to lime recovery with a flocculation pH greater than 11.0.

Table 7-5. EFFECT OF FLOCCULATION pH ON SECOND STAGE CAKE DRYNESS

pH	Total solids in cake, percent	
	Range	Median
11.2 to 11.5	11.0 to 14.4	11.8
11.0	15.5 to 19.6	17.2
10.2	13.7 to 20.3	18.4



Machine: Sharples P 3000
Pond: 4
Conveyor pitch, in: 3
Centrifugal force, g: 2100
Polymer: Atlasep 2A2

SYMBOL	FEED RATE gpm	CONVEYOR RPM	FEED, % SOLIDS	CAKE, % SOLIDS
⊙	29.0	11	1.6	15.5-17.4
⊡	14.0	6	1.5	16.8-19.0
△	11.0	4	1.6	16.4-18.0

Figure 7-18 Effect of feed rate on solids recovery

Sludge Recarbonation - Some lime sludge processing flow sheets include pH adjustment of the sludge with carbon dioxide ("recarbonation") prior to sludge processing. The purpose of recarbonation is to dissolve the magnesium hydroxide fraction which may hinder dewatering if left in the sludge.[1] Parker, *et al.*[3] investigated recarbonation of the sludge prior to second stage centrifugation. In general, there appeared to be little, if any, benefit derived from recarbonation of the first or second stage feed sludge. The lowest pH investigated by Parker *et al*. was 9.0. At this level there was essentially no magnesium hydroxide dissolved from the sludge. Therefore the findings of no change in sludge dewatering properties by these investigators is not surprising.

Thompson and Black[22] investigated dissolution of magnesium hydroxide from water treatment plant sludge. It was found that a pH of 7.3 was required for complete dissolution. They reported that the partial pressure of carbon dioxide determined the rate of magnesium dissolution. Considering the work of Thompson and Black,[22] it appears that future work on sludge recarbonation should be done with pH levels lower than that used by Parker, *et al*.[3] Special attention should be given to whether other materials (such as phosphate, calcium or organics) are released in the process. The effects of centrate return to the plant should also be evaluated.

Effect of Lime Recycle - Bennett evaluated lime sludge recalcination and reuse at the Blue Plains pilot plant on sludge generated from raw sewage coagulation.[9] Limited centrifuge data indicate a marked reduction in polymer requirements when reclaimed lime was reused. (See Fig. 7-19). The favorable influence on sludge dewatering of recycling the inerts with the reclaimed lime can be compared to the planned use of fly ash in other dewatering applications. Additional data from the Blue Plains pilot plant on centrate treatment is given in Table 7-6.

Table 7-6. DEWATERING OF HIGH LIME "IPC" SOLIDS AFTER CENTRIFUGE CLASSIFICATION

Dewatering Method	Lime Reuse	Feed Solids Conc., % TS	Loading	Cake Solids Conc., % TS	Chemical Cost, $/ton
Vacuum Filter	No	7.7	7.3-9.8 kg/sq m-hr (1.5-2.0 lb/sq ft-hr)	24-25	None
Filter Press[a]	No	7.5	1,169 kg/cu m (73 lb/cu ft) 197 min cycle	29-34	None
Centrifuge[b]	No	5.7	35-48 ton DS/day	14-16	4-5
Vacuum Filter	Yes	5.2	4.9 kg/sq m-hr (1.0 lb/sq ft-hr	25-26	None
Filter Press[a]	Yes	2.6	1,202 kg/cu m (75 lb/cu ft) 155 min cycle	34	None
Centrifuge[b]	Yes	6.6	35-50 ton DS/day	14-16	1-4

[a] Nichols 1 sq ft filter press

[b] Sharpless P600 centrifuge operated in high recovery mode.

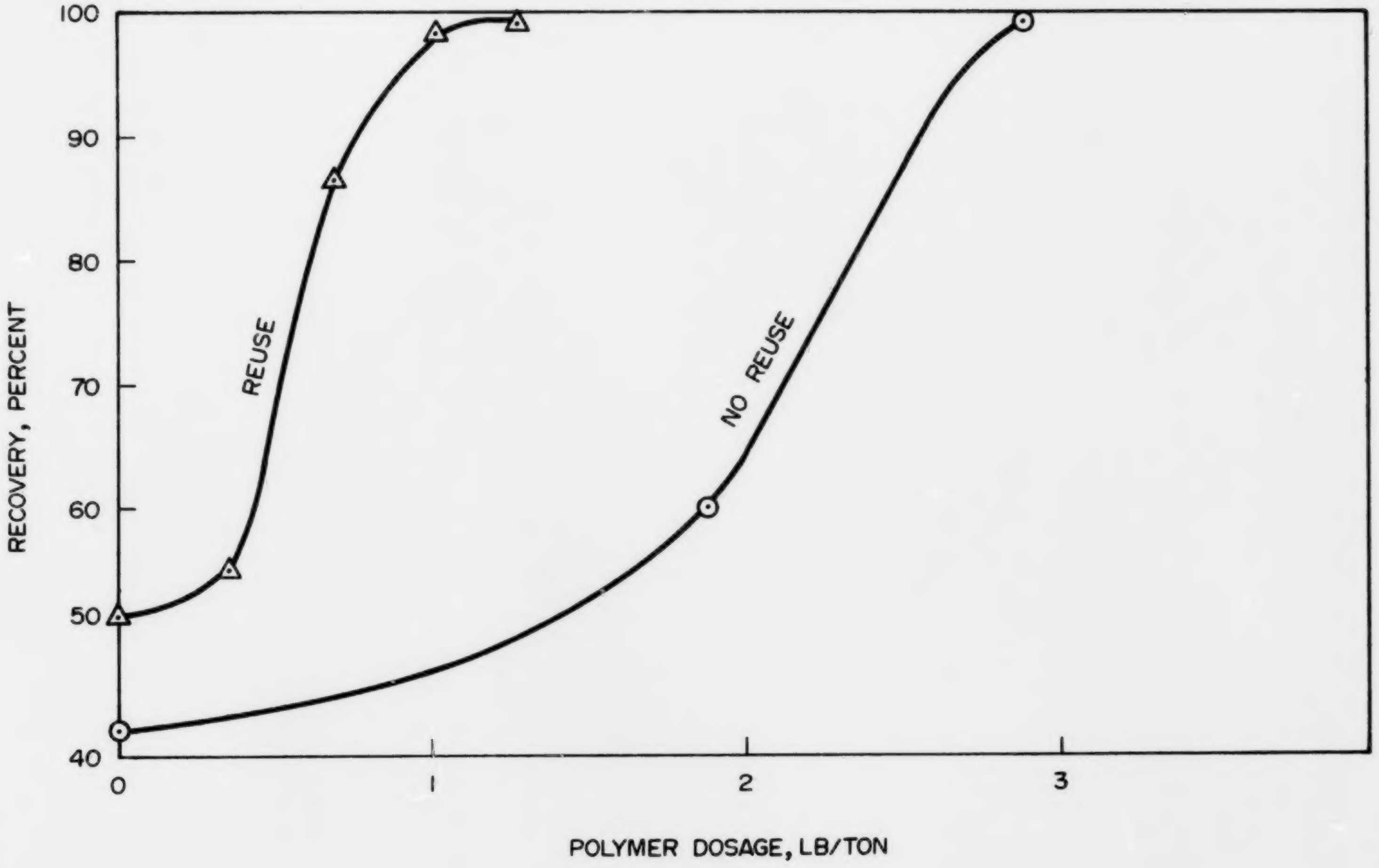


Figure 7-19 Effect of polymer dosage on lime recovery

Whole Sludge Recovery with Centrifuges -

In addition to its classification capability, a centrifuge can also be used for whole sludge recovery. A typical flow sheet for this application has been shown in Fig. 7-8. Typical data from the Blue Plains pilot plant on operation for whole sludge recovery is given in Table 7-7.

Table 7-7. DEWATERING OF "IPC" WASTE SOLIDS (WHOLE SLUDGE)

Sludge Source	Vacuum Filter		Centrifuge[a]			Filter Press[b]		
	Cake Solids, % TS	Loading, kg/sq m-hr (lb/sq ft-hr)	Cake Solids, % TS	Recovery, %	Cake Production, ton/day	Cake Solids, % TS	Cycle, hrs.	Bulk Density, kg/cu m (lb/cu ft)
IPC High Lime	35-36	30-45 (6-9)	28-32	98-99	43-90	44-45	1.0-1.2	1378-1794 (86-112)
IPC Low Lime	28-29	10-15 (2-3)	28-29	91-99	85-90	45-47	2.6-3.6	1250-1314 (78-82)

[a] Sharples P600 centrifuge in high recovery mode
[b] Nichols 1 sq ft filter press

Shuckrow and Bonner[23] have reported the results of dewatering tests on primary lime sludges in a 5.7 l/sec (90 gpm) pilot plant located in Cleveland. The pH of the centrifuge feed was 10.5. When the centrifuge was operated at 5,000 rpm (2,120 G), solids capture ranged from 50 to 80 percent solids and the solids concentration in the cake varied from 20 to 45 percent. Centrifuge performance at 3,500 rpm (1,020 G) produced only a one percent drop in cake solids concentration. Shuckrow and Bonner found that to increase solids capture to 95 percent, approximately 0.55 to 0.75 kg (1.2 to 1.7 pounds) of polymer per ton of dry solids were required. It was found that at 5,000 rpm the required polymer dose was 30 percent lower than at 3,500 rpm for equal centrate quality. Dewatered sludge solids content was dependent on solids capture; solids content averaged 26 percent at 70 percent capture and 22 percent at 90 percent capture when using polymer conditioning.

Brown and Caldwell[24] tested whole sludge recovery on sludge generated at pH 10.2 at the ATTF. In order to obtain 90 percent recovery at 2,000 G, it was necessary to use 0.7 to 0.9 kg of anionic polymer per ton of dry solids (1.5 to 2.0 lb/ton). Cake solids varied from 19.5 to 28.4 percent TS.

Sludges generated in a two-stage lime treatment system processing partially clarified raw wastewater have been tested at a 0.6 to 1.2 l/sec (10 to 20 gpm) pilot plant at the CCCSD treatment plant.[25] It was found that sludge generated at pH 10.2 dewatered more easily than sludges at pH 10.8. To obtain 90 percent recovery required 0.14 to 0.45 kg of anionic polymer per ton DS (0.3 to 1.0 lb/ton). Inspection of the data at pH 10.8 indicates that increasing the "G" level from 750 to 2,100 improved recoveries from 72 to 90 percent at a polymer dose of 0.17 kg per ton DS (0.38 lb/ton). Cake dryness was strongly related to recovery in the centrifuge. At 90 percent recovery, 24 percent TS in the cake was obtained; at 80 percent recovery, 28 percent TS was obtained; at 70 percent recovery, 33 percent TS was obtained; and at 60 percent recovery, 37 percent TS was obtained.

Smith[26] found that a pH of 10 was optimum for good centrifuge results on primary lime sludge. He obtained average cake concentrations of 33 percent and solids recoveries of 78 percent without the use of polymers. However, centrate quality was poor (1.3 percent SS). Addition of an anionic polyelectrolyte resulted in reductions of centrate solids in proportion to the polymer dose. Fig. 7-20 shows the effect of polymer addition on suspended solids removal.

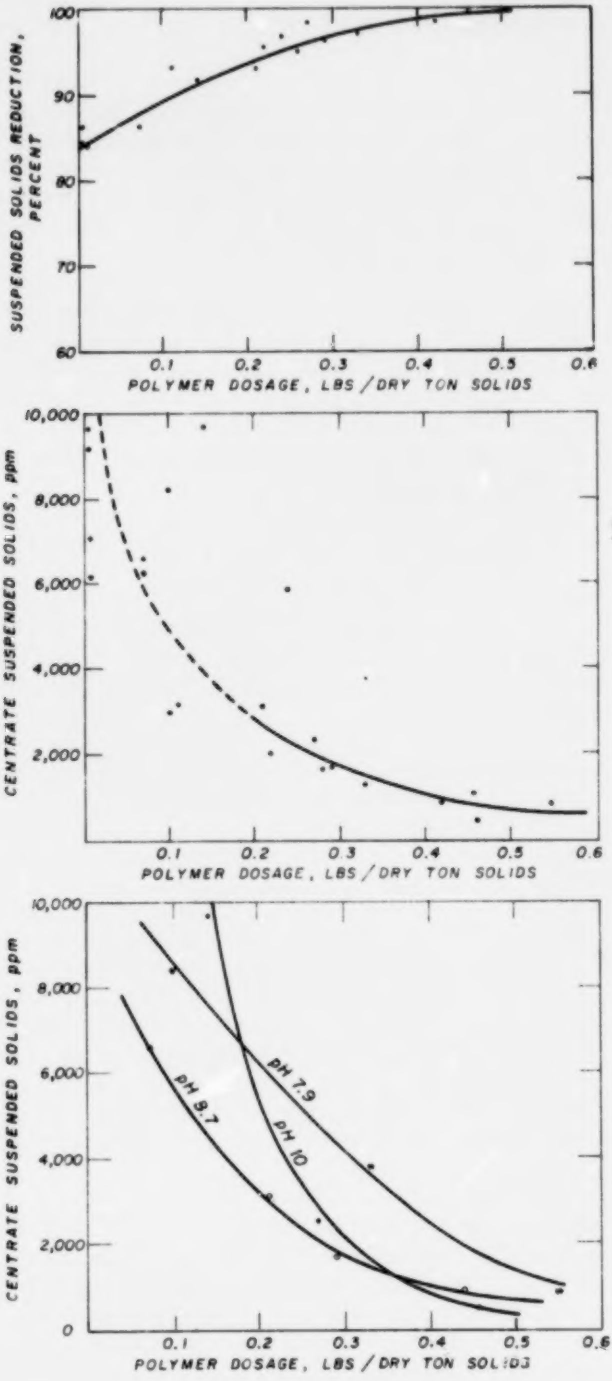
Tofflemire and Hetling[27] conducted centrifuge dewatering tests using primary sludge from a 0.3 l/sec (5 gpm) low lime pilot plant. Solids recoveries were excellent, ranging from 93 to 100 percent at a conveyor speed of 4,600 rpm and 86 to 100 percent at 5,000 rpm. The pH varied from 8.6 to 12.3. Contrary to the results obtained at Cleveland,[23] Tofflemire and Hetling found that, as long as fresh lime sludge was fed to the centrifuge, the addition of an anionic polymer did not appear to affect the recovery of solids.

Vacuum Filtration

Historically, vacuum filtration has found wide acceptance for dewatering municipal and industrial sludges. In the municipal field, the leading role of vacuum filters has only been recently challenged by the increasing use of centrifuges in sludge dewatering applications. An excellent review of the theory of sludge filtration is given in Reference 10.

Basically, a vacuum filter consists of a rotating drum partially (20 to 40 percent) submerged in a sludge tank or pan. The drum cylindrical surface is covered with the filter medium and a vacuum of about 25 to 65 cm (10 to 26 inches) of Hg is applied between the drum compartments and the filter medium. As the drum passes through the pool of sludge, solids are attracted to the drum surface by the vacuum effect forming a sludge mat (filter cake). Moisture (filtrate) is extracted and filtered through both sludge cake and filter medium. As the drum rotates, the captured solids undergo further dewatering. Before the next pick-up and dewatering cycle begins, filter cake is scraped off the drum surface and falls into a mechanical conveyor. This conveyor then carries the dewatered sludge to a loading area, to storage, or to further processing stages. The filtering medium is usually a cloth or metal belt (belt-type filters), or a double layer of stainless steel coil springs (coil-type filters). Several variations of these basic designs are also available. Fig. 7-21 show a typical belt-type filter.

The performance of a given vacuum filter installation depends both on the sludge characteristics and on the filter operating variables. Sludge type, age, solids concentration, and chemical composition are some of the sludge characteristics that affect the vacuum filtration process. Operating variables include applied vacuum, filter submergence, chemical conditioning, type of filter media, and drum rotational speed. All these sludge and operating variables influence



CENTRIFUGE CONSTANTS

Feed Rate - 24 GPM
Bowl RPM - 3250
RPM - 27
Pond Depth - 3½

Figure 7-20 Effect of polymer dosage on solids removal

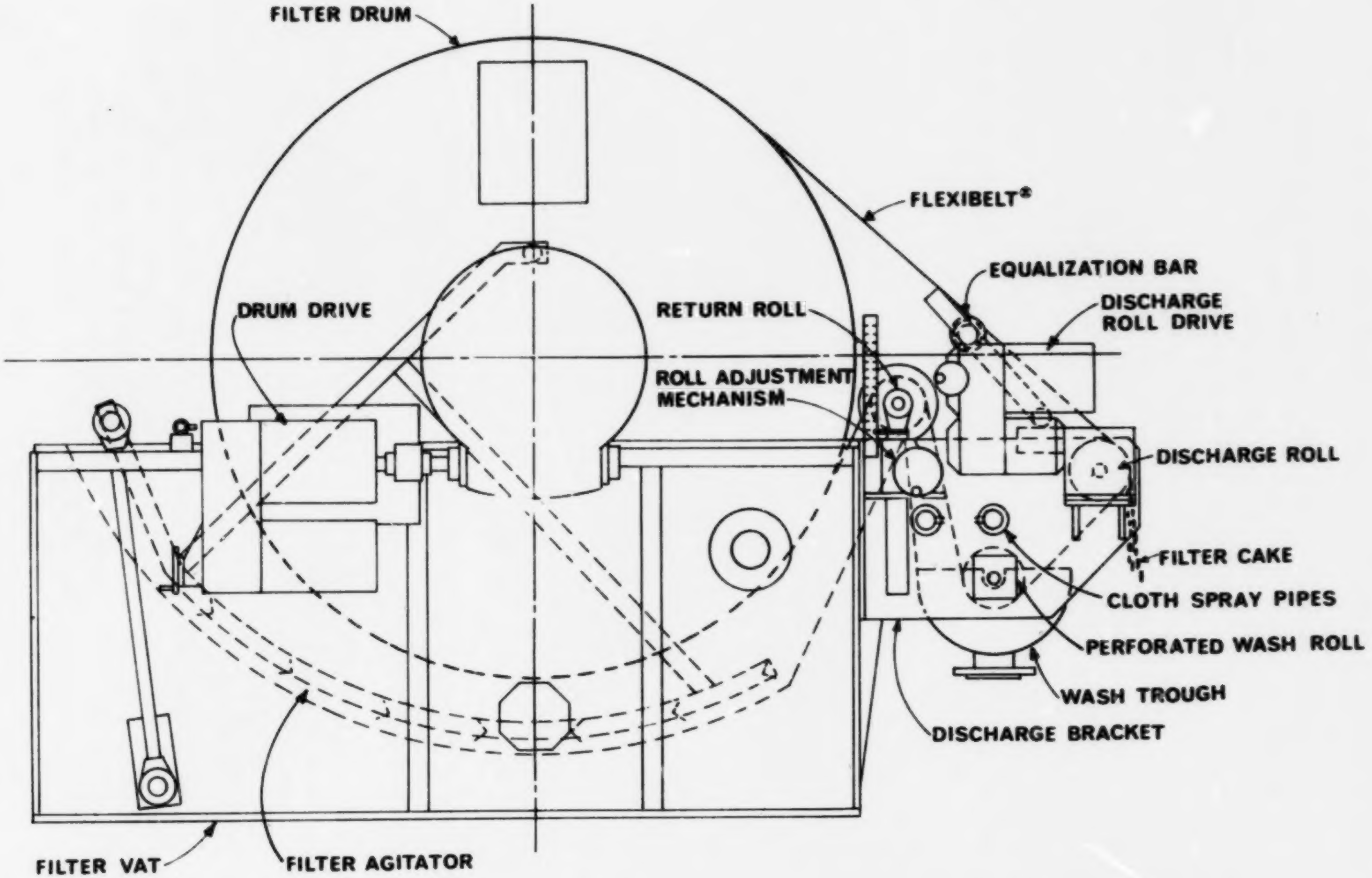

FILTER DRUM
FLEXIBELT®
EQUALIZATION BAR
DISCHARGE ROLL DRIVE
DRUM DRIVE
RETURN ROLL
ROLL ADJUSTMENT MECHANISM
DISCHARGE ROLL
FILTER CAKE
CLOTH SPRAY PIPES
PERFORATED WASH ROLL
WASH TROUGH
DISCHARGE BRACKET
FILTER VAT
FILTER AGITATOR

Figure 7-21 Schematic diagram of a belt type vacuum filter (courtesy of Komline-Sanderson Engineering Corporation)

the filtration process performance expressed in terms of sludge cake moisture content, solids recovery, cake thickness, filter yield, and filtrate clarity.

Although lime has been intensively used in vacuum filtration of sludges, either alone or, more commonly, coupled with ferric chloride, its role has been primarily as a conditioning agent to improve the dewatering and handling characteristics of the sludge. Dewatering of primary generated lime sludges by vacuum filtration is a far less common practice. Burns and Shell[6] conducted numerous vacuum filter tests, using the test leaf method,[10] on both moderate (< 11.0) and high (> 11.5) pH treatment sludges. The results of these tests, adjusted by a scale up factor, together with the operating conditions, are given in Fig. 7-22. Conditioning the sludge with 0.09 to 0.27 kg (0.2 to 0.6 lb) of anionic polymer per ton of dry solids increased the vacuum filter yields from 30 to 70 percent above the values obtained from Fig. 7-22.

Mulbarger _et_ _al_.[1] used filter leaf tests following gravity thickening to determine the dewatering characteristics of lime sludges during bench scale studies of lime clarification, recovery, and reuse. The sludges had been produced by lime treatment of secondary effluent. Two-stage treatment was selected for study at a pH equal to or larger than 11. The investigators found that reclaimed limes produced sludges which were easier to filter than new lime sludges. They attributed this to the presence of recycled inerts acting as a filter aid. Filter cake solids varied between 28 and 45 percent for the range of lime dosage studied. Recovery efficiencies of the gravity thickener-vacuum filter system for total solids, calcium, phosphorus, and magnesium varied between 96 and 100 percent (without sludge carbonation).

Leaf tests on polymer conditioned centrate from a centrifugal classification step were conducted at the CCCSD's ATTF. The centrate was difficult to dewater and resulted in extremely low filter yields, ranging from 1.75 to 2.20 kg/sq m/hr (0.36 to 0.45 lb/sq ft/hr). The feed solids concentration was only 2.4 percent. Other tests produced even lower filter yields, ranging from 0.98 to 1.46 kg/sq m/hr (0.2 to 0.3 lb/sq ft/hr). Also, the discharge characteristics of the filter cake were poor.[3]

Best media in the ATTF tests on centrate was a synthetic fabric (Eimco Dynel DY453). The centrate solids did not contain enough fibrous material to allow solids capture on the coil filter medium tested.

Whole high-lime sludge (pH 11) was somewhat easier to dewater, with filter yields ranging from 8.8 to 13.2 kg/sq m/hr (1.8 to 2.7 lb/sq ft/hr) without polymer conditioning. These yields are consistent with the data of Burns and Shell (Fig. 7-22) since the feed solids for the ATTF tests ranged from 3.0 to 3.6 percent total solids.

Investigators at Blue Plains have extended considerable effort towards defining vacuum filtration operating parameters for lime sludge generated by an independent physical-chemical system (IPC).[9] The IPC System consisted of lime coagulation, flocculation, sedimentation, filtration, and activated carbon adsorption. Vacuum filtration data on whole primary sludge are shown in

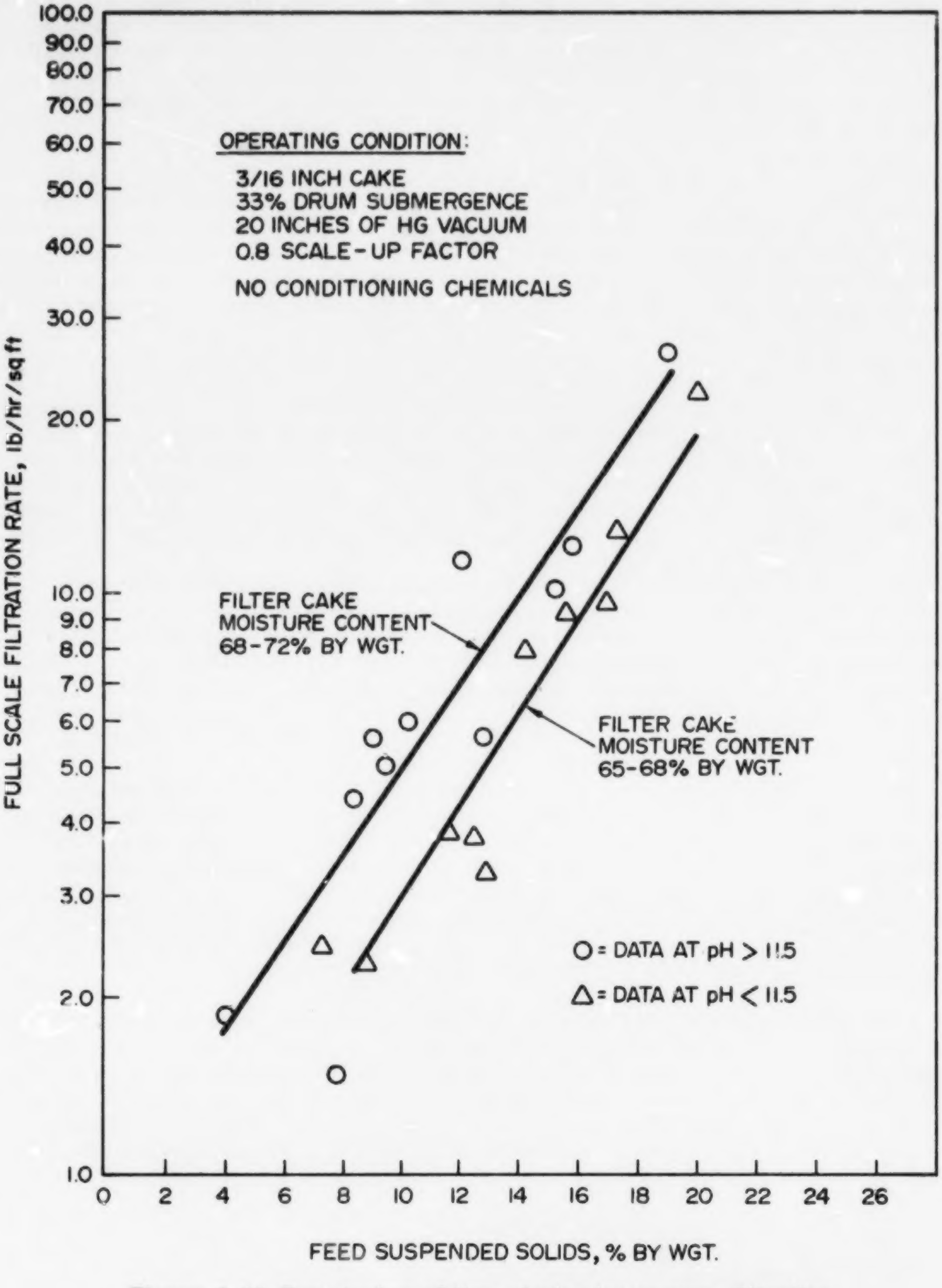


Figure 7-22 Dewatering of lime sludge by vacuum filtration

Table 7-7. Consistent with the experience of Burns and Shell,[5] high lime sludge filtered at a higher rate than low lime sludge. Similar experience was gained at Blue Plains on centrate (Table 7-6), as found at the ATTF. Filter yields were higher, 4.9 to 9.8 kg/sq m-hr (1.0 to 2.0 lb/sq ft/hr) compared to 0.98 to 2.2 kg/sq m/hr (0.20 to 0.45 lb/sq ft-hr) at the ATTF, but feed solids were greater at Blue Plains as a result of flotation thickening.

In summary, the leaf-test data of Burns and Shell (Fig. 7-22) stand up well compared to the results of other investigators and can be used for design purposes on vacuum filters treating lime sludge from primary applications. However, two features on Fig. 7-22 should be highlighted. First, there is variation in filtration rates above and below the trend lines shown, reflecting day-to-day variations in sludge characteristics. Since sludge quality will be subjected to variations, some conservatism in the application of Fig. 7-22 is justified. The other design factor apparent in Fig. 7-22 is that the filtration rate is strongly affected by feed solids concentration. To obtain an economic filter loading, for example 24 kg/sq m/hr (5 lb/sq ft/hr), the feed solids concentration must be between 10 and 13 percent total solids. This requires consistent performance out of the preceding thickening step. If thickener performance should deteriorate, the allowable vacuum filter loadings would be lower, and the sludge inventory will build up in the thickener. This in turn might result in further thickening deterioration. Standby vacuum filtration capacity should be provided to avoid overloading of filters.

While both Burns and Shell[5] and the Blue Plains investigators[9] found that polymer conditioning was not required for vacuum filtration of whole sludge, others have reported the need for polymer addition. Shuckrow and Bonner[23] conducted pilot studies of lime sludge in a 3 ft diameter belt drum filter. Raw sludges had been generated at a clarifier pH ranging from 10.0 to 12.2. They found that vacuum filter performance was dependent on influent solids content, polymer dose, and drum speed. The effect of these parameters is plotted in Figs. 7-23, 7-24, and 7-25 for sludges generated at pH 10.5. Cake solids ranged from 19 to 36 percent dry solids and filter loadings rates varied from 14.6 to 92.8 kg/sq m/hr (3 - 19 lb/sq ft/hr). Cake solids content was mainly dependent on filter loading rate. The addition of less than 0.9 kg (2 lbs) of polymer per ton of dry solids allowed loading rates up to three times higher than without polymer conditioning. Maximum loading rates were obtained at the fastest drum speeds (50 rph), but a wetter cake was produced causing it to adhere to the filter medium. Solids capture was found to be strongly dependent on solids content and only slightly dependent on drum speed.

It is recommended that facilities for polymer conditioning be provided to be used in case actual operation demonstrates this need. Polymer conditioning is sometimes required periodically only, as is often found in treatment plants receiving seasonal industrial wastes. In any event, facilities for polymer addition provide flexibility of operation and a margin of safety in case that changes in sludge characteristics might occur. An additional benefit of polymer conditioning is that, by increasing the filter loading, it allows reduction of the filter area required.

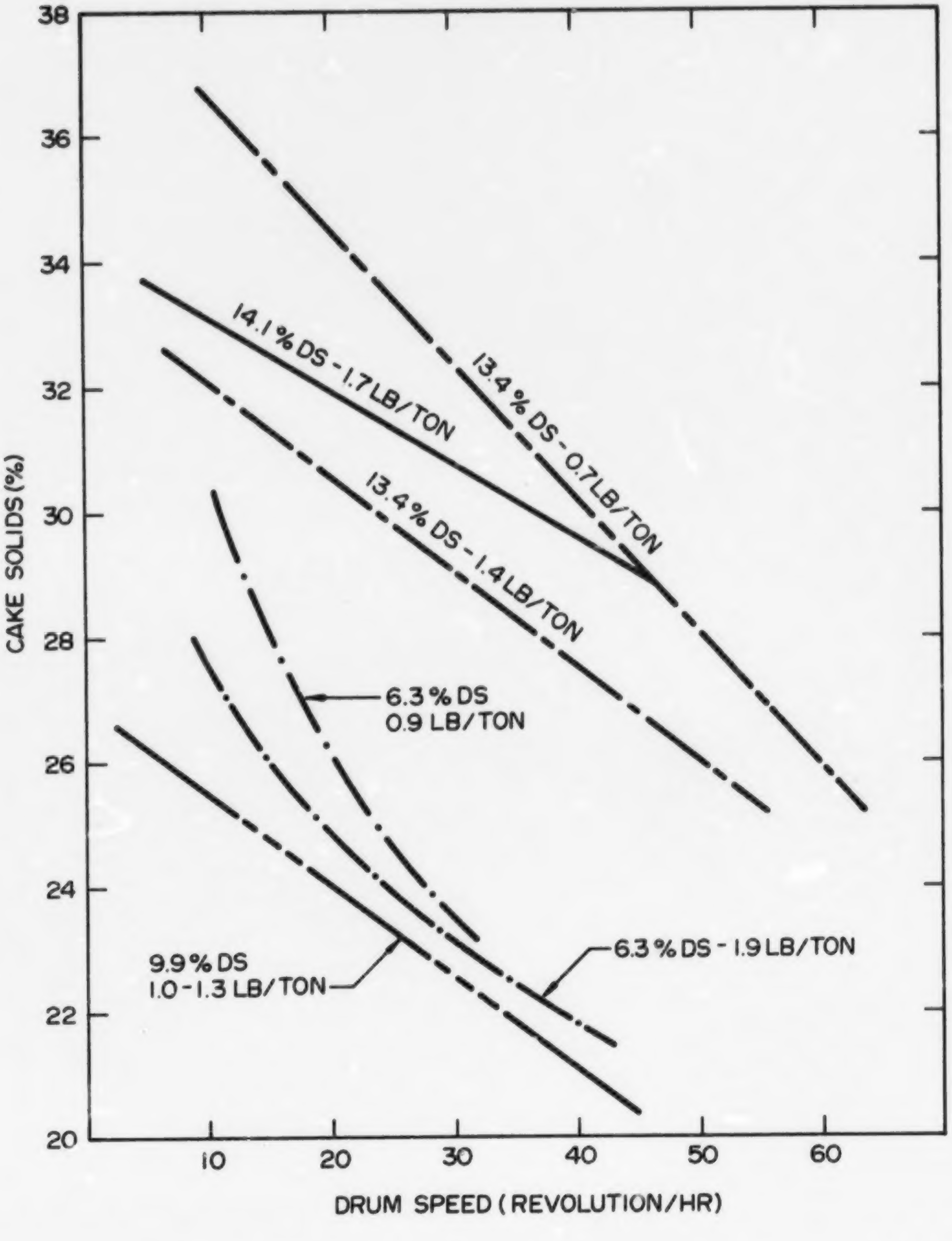


Figure 7-23 Effect of drum speed on cake solids concentration

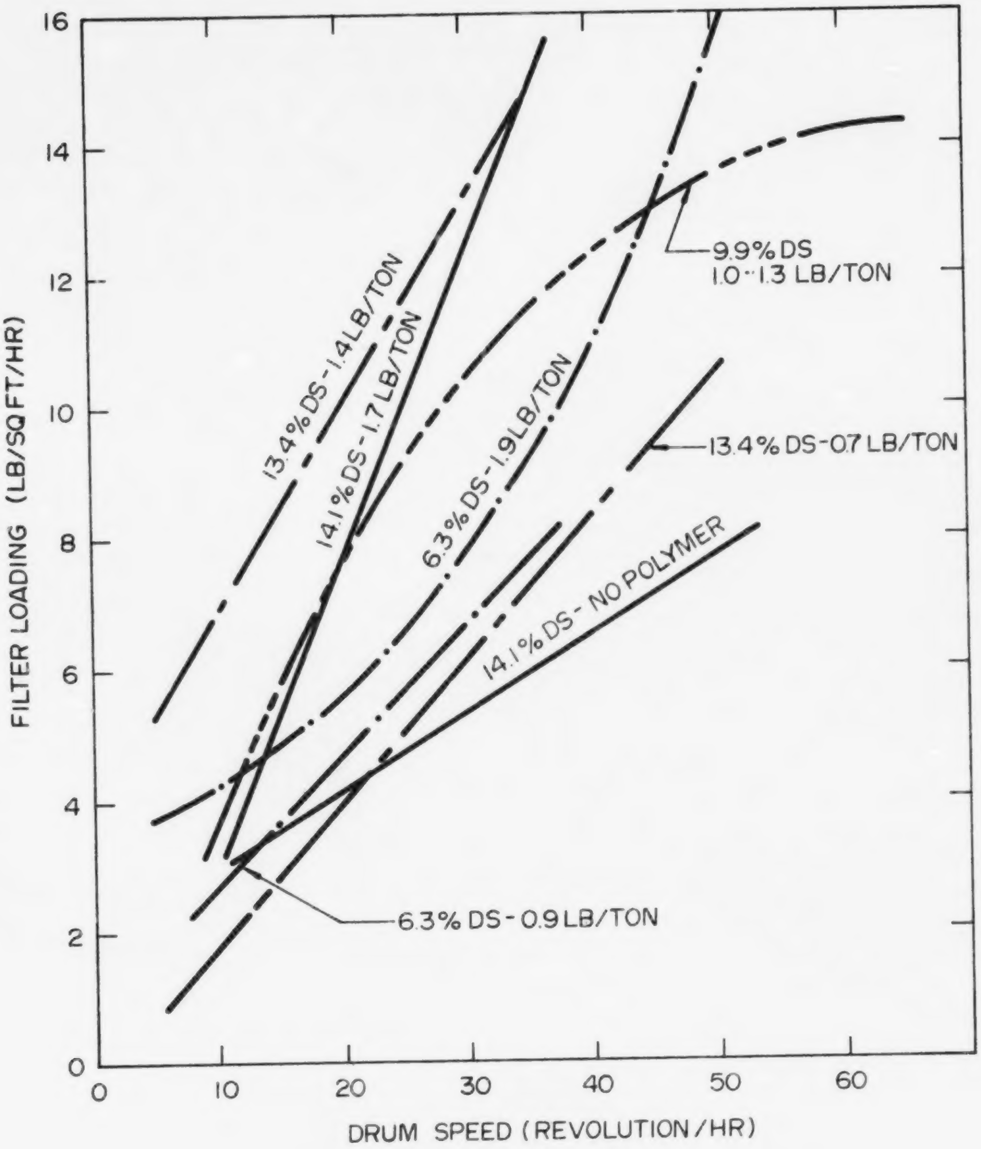


Figure 7-24 Effect of drum speed on filter loading

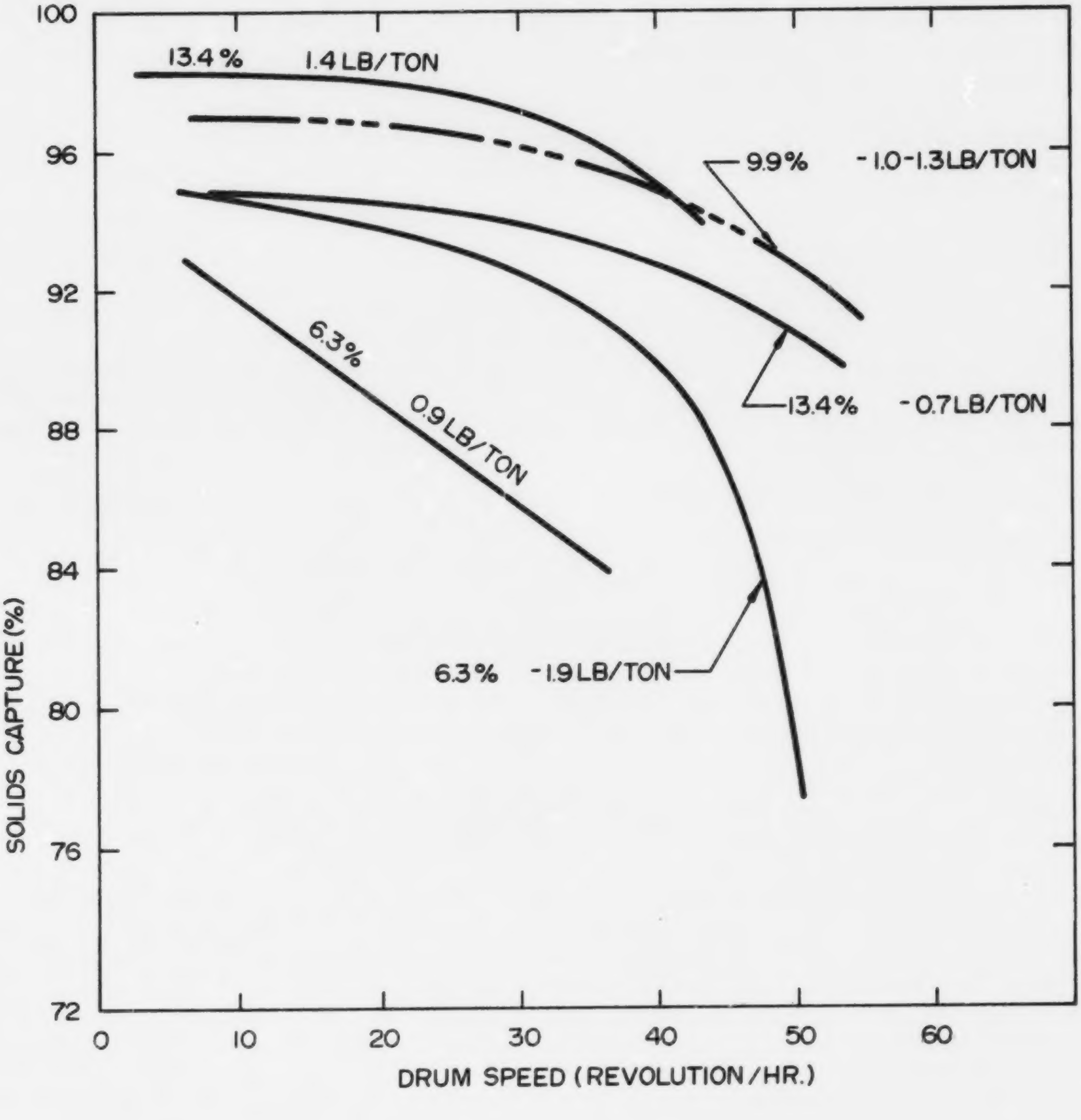


Figure 7-25 Effect of drum speed on solids capture

Although vacuum filtration seems to yield fairly dry cakes and achieve excellent solids recovery, it does not permit classification of the sludge constituents prior to lime calcination. Consequently, a large proportion of inerts and other undesirable solids are recycled through the treatment processes. The amount of recycled solids can be decreased either by wasting reclaimed lime ("blow down") or by dry classification of the recalcination product. However, wet classification is a more efficient process to separate calcium carbonate from the undesirable components of the sludge cake.

Vacuum filtration of centrate from a classification step does not appear to be economically attractive, since filter loading rates are so low. and the cake discharge properties are poor.

Pressure Filtration

Filter presses are used extensively to dewater sludges from the chemical process industry. As indicated before, they have been used mostly in Europe for dewatering municipal sludges. In the U.S., pressure filtration has found limited application in the water treatment field to dewater coagulant (i.e., alum) sludges[28] and in the wastewater field to dewater a digested mixture of primary and trickling filter sludges.[29]

Steward[30] has listed two installations where filter presses are being used to dewater lime sludges and one that treats a lime and ferric chloride sludge. Although in two or these plants the sludge cake is incinerated, no attempt has been made to recalcine and reuse the lime.

Pressure filtration is a batch process. Basically, the process utilizes a high pressure differential up to 15.8 kg/sq cm (225 psig) to produce a sludge cake ranging between 30 and 65 percent solids. Sludge is fed to a series of filter plates lined with the filter medium which typically has been precoated with a filter aid, commonly fly ash. The filter feed system is designed to satisfy initial high volume-low pressure and final low volume-high pressure requirements. Normally, the average dewatering cycle takes less than two hours, after which the hydraulic pressure is relieved and the filter opened. The cake formed inside the chamber then drops, through cutting bars, directly to a loading truck or, more commonly, onto a belt conveyor underneath the filter. If the cake is to be incinerated, the conveyor discharges it into a storage bin. Since stored cake will tend to bridge over the discharge opening and, in the case of the wetter cakes, to adhere to the bin walls, the design of the storage facilities deserves special attention. Fig. 7-26 shows a schematic diagram of a pressure filtration system. Media conditioning by placing a protective layer of porous material on the filter media before the dewatering step is often practiced to prevent premature blinding of the filter. (Ash from a sludge incinerator can be used as a pre-coat material, see Section XI).

In lime recovery application, filter presses have the same limitation that vacuum filters do, namely, their inability to classify the sludge solids prior to incineration. They present the added disadvantages of intermittent operation coupled, in some systems, with the need to clean the filter media after every cycle and to

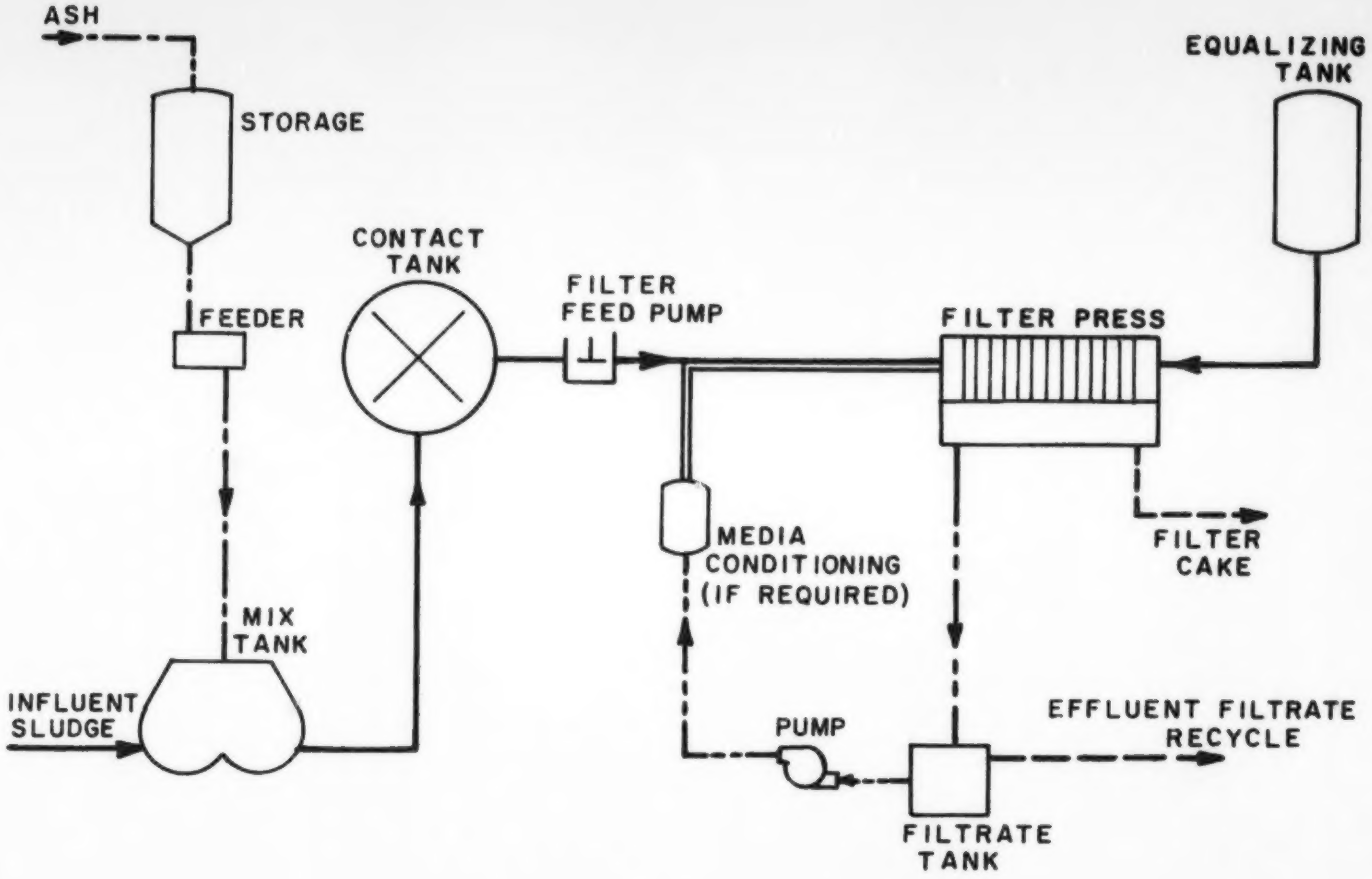

ASH
STORAGE
FEEDER
MIX TANK
INFLUENT SLUDGE
CONTACT TANK
FILTER FEED PUMP
MEDIA CONDITIONING (IF REQUIRED)
PUMP
FILTER PRESS
EQUALIZING TANK
FILTER CAKE
FILTRATE TANK
EFFLUENT FILTRATE RECYCLE

Figure 7-26 Schematic diagram of a pressure filtration system (courtesy of Passavant Corporation)

pre-coat it before the next dewatering cycle can start. These drawbacks are partially offset by the fact that the entire process can be automated.[30] Data on a whole sludge application are shown in Table 7-7.[9]

The greatest potential for pressure filtration in lime sludge applications seems to lie in the dewatering of first stage centrate. Bennett[31] has reported filtrate solids concentrations greater than 30 percent obtained on a 1 sq ft pilot filter press operated at 7 kg/sq cm (100 psi). The pH of the lime sludge fed to the classifying centrifuge was 11.5. Cake discharged from the filter press without difficulty and no conditioning chemicals were required. Tables 7-6 and 7-8 present data obtained at the Blue Plains pilot plant on centrate filtration. One of the principal advantages of pressure filtration is evident in Table 7-8, namely high filtrate clarity. Lime recycle appears to reduce the cycle time required for pressure filtration (Table 7-8). Apparently, the recycling of lime to the primary sedimentation tank is equivalent to the use of fly ash for sludge conditioning in terms of its effect on filter performance. Comparable results have been obtained at the CCCSD's ATTF on centrate (Table 7-9). Both the cycle time and the obtainable cake solids are lower than obtained at Blue Plains when no lime was recycled; this difference is likely due to differences in quality of the sludges.

Comparison of Dewatering Techniques

As introduced at the beginning of this section, there are several approaches to sludge dewatering. The method of dewatering has a marked impact on the recovery of lime. Of the alternatives considered, only the solid bowl centrifuge allows control over the amount of inerts recycled in the process. If a vacuum filter or filter press is utilized, furnace products must be blown down to control inerts which cause a loss of reclaimed lime.

Equipment Requirements -

To compare equipment requirements for the alternate flowsheets (Figs. 7-8 and 7-9), Table 7-10 was prepared. To lend some reality to the comparison, actual manufacturers' equipment models were used for illustration purposes. In all cases, the model chosen was the largest unit made by the manufacturer. This reduced the total number of machines required for each alternate. Machines of other manufacturers having similar sludge processing capacity may be substituted for those listed in the table.

In the ATTF flowsheet, two types of solid bowl centrifuges are given for the first dewatering function, vertical and horizontal. In the second stage dewatering step, vacuum filtration and filter pressing are presented as alternates. In the Plural Purpose Furnace flowsheet, centrifugation, vacuum filtration, and filter pressing alternatives are illustrated. The centrifugation alternatives are based on those included in the plans and specifications for the CCCSD Water Reclamation Plant.[11] The filter pressing alternatives are based on CCCSD and Blue Plains data (Tables 7-8 and 7-9). Second stage vacuum filter loading is based on ATTF and Blue Plains data.[31] Vacuum filtration of whole sludge is based on Cleveland Westerly data (Figs. 7-23, 7-24, and 7-25).[23]

Table 7-8. PRESSURE FILTRATION OF CENTRATE AT BLUE PLAINS

Run No.	Feed solids, %	Cake solids, %			Filtrate solids, %		Cycle hrs	Bulk density kg/cu m (lb/cu ft)	No. of cells
		Outside	Middle	Inside	SS, mg/l	TS, mg/l			
1. No lime recycle, thickened by flotation	7.3	33.1	29.9	26.6	60	-	3.32	1195 (74.6)	3
2. No lime recycle, thickened by flotation	7.7	34.6	37.3	32.4	-	-	3.30	1149 (71.7)	3
3. Lime recycle, no thickening	2.6	30.3	34.0	26.6	47	-	2.58	1202 (75.0)	1
4. Only one recycle of lime, thickened by centrifugation	3.7	31.2	28.2	27.6	106	1212	3.75	1158 (72.3)	2
5. Only one recycle of lime, thickened by centrifugation	9.8	31.8	31.6	31.1	644	1630	1.34	1173 (73.2)	2
6. With one recycle, thickened by flotation (2)	4.7	31.1	29.0	26.5	228	588	2.5	1136 (70.9)	2

Temp. 11-15 C, (52-50 F) operating pressure 7 kg/sq cm (100 psi) test performed on 0.09 sq m (1 sq ft) Nichols pilot filter press (2) thickened in the pilot 1 sq ft dissolved air flotation unit.

Table 7-9. PRESSURE FILTRATION OF CENTRATE AT CCCSD

Run no.	Filter[a] cycle time, hr	Feed solids, percent	Cake solids, percent	Feed pH[c]	Cake thickness, cm (inch)
1	2.75	4.1	26.5	10.75	2.54 (1.0)
2[b]	2.0	3.4	24.1	12.0	2.54 (1.0)
3	2.2	4.1	24.6	10.75	2.54 (1.0)
4	3.0	3.3	23.0	10.4	3.18 (1.25)
5[b]	2.5	3.4	26.6	11.9	3.18 (1.25)
6	2.0	3.4	24.8	10.8	2.54 (1.0)

[a] Tests performed with a Nichols 0.09 sq m (1 sq ft) filter press at 7 kg/sq cm (100 psig).

[b] Tests performed with the addition of dry classification rejects on an 8 percent dry weight basis.

[c] Primary sedimentation operated at pH 10.8.

Table 7-10. COMPARISON OF MACHINE AND FLOOR AREA REQUIREMENTS FOR ALTERNATE FLOW SHEETS AT 1.31 CU M/SEC (30 MGD)

Flow sheet	First stage sludge dewatered, kg/day (lb/day)/ percent TS	Machine	Loading, metric (English)	No. units required	Floor area,[b] sq m (sq ft) each/total	Second stage sludge dewatered,[a] kg/day (lb/day)/ percent TS	Machine	Loading, metric (English)	No. units required	Floor area,[b] sq m (sq ft) each/total	Total floor area, both stages sq m (sq ft)	Total no. of[g] machines[c] (both stages)
CCCSD's ATTF[d] at pH 11.0	101,729 (224,312)/8	Centrifuge: Sharples P6800[e]	14.4 l/sec (221 gpm)	1	6.9 (74)/ 6.9 (74)	38,258 (84,363)/4	Centrifuge: Sharples P6800[e]	10.9 l/sec (172 gpm)	1	6.9 (74)/ 6.9 (74)	13.8 (148)	2
	98,806 (217,875)/8	Centrifuge: Sharples P6800[e]	13.6 l/sec (215 gpm)	1	6.9 (74)/ 6.9 (74)	36,219 (79,865)/4	Vacuum filter Elmco belt 12 x 20	4.9 kg/sq m-hr (1 lb/sq ft-hr)	5	28.5 (307)/ 142.5 (1,535)	149.4 (1,609)	6
	96,783 (213,414)/8	Centrifuge: Sharples P6800[e]	13.3 l/sec (211 gpm)	1	6.9 (74)/ 6.9 (74)	35,132 (77,469)/4	Filter press Nichols 72" x 48"	25% TS, 2.25 hr cycle	3	25.7 (276)/ 77.1 (828)	84 (902)	4
	101,725 (224,312)/8	Centrifuge: Sharples P5400[f]	14.4 l/sec (221 gpm)	1	17.7 (191)/ 17.7 (191)	38,259 (84,363)/4	Centrifuge: Sharples P5400[f]	5.4 l/sec (86 gpm)	2	17.7 (191)/ 35.4 (382)	53.1 (573)	3
Plural purpose furnace[d] at 20% ash blowdown	133,064 (293,415)/8	Centrifuge: Sharples P6800[e]	18.2 l/sec (289 gpm)	1	6.9 (74)/ 6.9 (74)	-	-	-	-	-	6.9 (74)	1
	132,843 (292,928)/8	Vacuum filter Elmco belt 12 x 20	39 kg/sq m-hr (8 lb/sq ft-hr)	2	28.5 (307)/ 57.0 (614)	-	-	-	-	-	57.0 (614)	2
	126,835 (279,680)/8	Filter press Nichols 72" x 48"	45% TS, 1.2 hr cycle	3	25.7 (276)/ 77.1 (828)	-	-	-	-	-	77.1 (828)	3

[a] See Section X for solids balances.

[b] Machine only, not including ancillary equipment such as chemical feed equipment, cake conveying equipment, piping, etc.

[c] Standby equipment is not included, normal practice requires standby capacity.

[d] Two furnaces are required.

[e] Vertical machine.

[f] Horizontal machine.

[g] Number of units per furnace.

Comparing flowsheets, it can be seen from Table 7-10 that less dewatering equipment is required for the Plural Purpose Furnace flowsheet than for the ATTF flowsheet. Among the Plural Purpose Furnace flowsheet alternates, the least floor area is required for the centrifuges. This reflects more compact equipment arrangements possible with centrifuges. Among the ATTF flowsheet alternatives, the centrifuges also require the least number of machines and the least total floor area. The floor area requirements for ancillary equipment, e.g., sludge conditioning equipment, feed pumps, etc., are considered similar for each alternative and are not included in the comparison. As a general rule, floor requirements for auxiliary systems usually exceed those for the dewatering machines themselves.

Maintenance -

Maintenance requirements will differ among the machine alternates and are difficult to quantify. High speed centrifugals, even with hard surfacing of the conveyor, will require periodic resurfacing. The operating period between overhauls will depend on the amount of sandy material contained in the feed sludge. Efficient grit removal is of paramount importance when dewatering with centrifuges. Vacuum filter belt and the filter medium in filter presses require routine cleaning and may eventually have to be replaced. Their service life, however, is usually not affected by grit. Pressure filtration, even with the degree of automation provided in today's systems, requires more operator attention than vacuum filtration or centrifugation. The presence of an operator is recommended during the cake discharge cycle to make sure that all filter cakes drop from the press plates.

Relative Dewatering -

The alternatives must also be evaluated in terms of the basic dewatering objective, water elimination. This objective receives special emphasis when incineration follows dewatering, as approximately 450 kcal (1,800 Btu) are required to evaporate a pound of water (at off-gas temperature of 700 F). Table 7-11 has been prepared which presents an analysis of the weight of water which must be evaporated in the furnaces for each alternate presented in Table 7-10. Comparing the results for the ATTF flowsheet to the results for the Plural Purpose Furnace flowsheet, it can be seen that there is no disadvantage in incorporating the wet classification process into the ATTF flowsheet in terms of the energy required to evaporate water. In fact, there is a considerable advantage to the ATTF flowsheet.

Employing pressure filtration in the second dewatering stage of the ATTF flowsheet has a substantial advantage over vacuum filtration or centrifugation in terms of the energy required for incineration. This factor will no doubt encourage wider utilization of pressure filtration in this energy-conscious age.

Flexibility -

The centrifugation process has demonstrated greater stability to changes in influent characteristics than either the vacuum filtration process or pressure filtration. This is partially indicated by the effect of influent solids level on

Table 7-11. COMPARISON OF WATER EVAPORATED FOR ALTERNATE DEWATERING SYSTEMS AT 1.31 CU M/SEC (30 MGD)

Flow Sheet and Dewatering	Dry Solids Burned in First Stage, kg/day (lb/day)	Percent Total Solids	Water Evaporated First Stage, kg/day (lb/day)	Dry Solids Burned in Second Stage, kg/day (lb/day)	Percent Total Solids	Water Evaporated Second Stage, kg/day (lb/day)	Total Water Evaporated kg/day (lb/day)
ATTF[a] 1st: centrifuge 2nd: centrifuge	62,977 (139,950)	58	46,961 (101,343)	33,136 (73,614)	17	162,998 (359,410)	209,960 (460,753)
ATTF[b] 1st: centrifuge 2nd: vacuum filter	62,104 (138,011)	58	45,323 (99,939)	33,782 (75,073)	20	136,187 (300,292)	181,510 (400,231)
ATTF[c] 1st: centrifuge 2nd: filter press	61,653 (135,945)	58	44,645 (98,443)	34,782 (76,694)	25	104,346 (230,002)	148,991 (306,776)
Plural Purpose Furnace[d] centrifuge	126,204 (278,281)	24	399,648 (881,223)	-	-	-	399,468 (881,223)
Plural Purpose Furnace[e] vacuum filter	126,204 (278,281)	28	324,526 (715,580)	-	-	-	324,526 (715,580)
Plural Purpose Furnace[f] filter press	126,204 (278,281)	44	160,624 (354,176)	-	-	-	160,624 (354,174)

[a] Case 100, Section X
[b] Case 101, Section X
[c] Case 102, Section X
[d] Case 106, Section X
[e] Case 114, Section X
[f] Case 117, Section X

filter yield for vacuum filters shown in Fig. 7-22 and the effect of influent concentration on cycle time for pressure filters in Table 7-8. This makes the vacuum filters and pressure filters more dependent on the uniformity of operation of upstream thickening process than the centrifuge.

Choice -

Choice of the dewatering process must be based on evaluation of all the factors listed in this section, past experience and preferences of the operating agency and the consulting engineer, operator competence and training, economics and local factors. The relative ranking of these factors may be different for many situations and lead to quite different solutions. The multiplicity of dewatering designs in evidence today is testimony to the variability in solutions.

SLUDGE CAKE CONVEYING

Sludge cake can be pumped or transported by mechanical or pneumatic methods. First stage centrifuge cake is usually too dry to be handled by pumps. Attempts to convey first stage cake from the ATTF with a progressive cavity, positive displacement pump were unsuccessful. Second stage cake, however, having the consistency of a slurry, can be pumped with positive displacement units. Centrifugal, torque-flow pumps have also been used to handle lime sludge. Aldworth[32] has reported the use of this type of unit to recirculate lime sludges of up to 28 percent solids concentration, in digestion tanks. He recommended abrasion-resistant construction for this application.

Mechanical conveyors are similar to the ones used to move dry materials (see Section V). Belt and screw conveyors and bucket elevators are often employed to transport the wet sludge cake to storage or to feed it to the incinerator. Screw conveying gave satisfactory results at the ATTF. "Totally enclosed" conveyor designs are also available. This type of mechanical conveyor features a series of flights dragged by one or two hardened chains. The conveying flights are enclosed in a rectangular casing. The return flights may be housed in the same casing or in a separate one. Apart from the advantage of enclosed transport of sludge cake, this conveyor is designed to change directions, a capability not possessed by conventional belt or screw conveyors. The degree and extent of directional changes varies among the various designs. As it was pointed out in Section V, selection of mechanical conveyors should be done in consultation with the equipment manufacturers.

The pneumatic conveying equipment used in wet sludge applications is of the pressure vessel (i.e., pneumatic ejector) type. Pneumatic ejection of sludge cake offers several advantages. The material is completely enclosed and can be conveyed in any direction, above or below grade. The flexibility of transport is particularly advantageous in multiple hearth furnace applications since it permits locating the dewatering equipment at or near ground level instead of above the top (feeding) hearth. The saving achieved by eliminating the elevated structures required to support the dewatering equipment can be substantial.

The key to successful application of pneumatic conveying techniques to sludge cakes lies in the characteristics of the sludge. Although cakes at solid concentrations of 40 to 50 percent DS have been successfully handled in pneumatic ejectors,[33] some sludges are difficult to expel from the vessel. In these cases, the compressed air usually blows holes through the sludge mass instead of forcing it through the discharge opening. Some manufacturers of pneumatic conveying equipment have pilot plant facilities[33] where the suitability of the sludge to pneumatic handling can be tested.

In sizing sludge conveyors, the specific weight of the material is often required. Fig. 7-27[34] was developed for converting from mass loading rates to volumetric loading rates. The data presented is for dense high calcium carbonate cake. In those cases where the cake is crumbled prior to transport and air is entrapped, a rule of thumb is to reduce the specific weight by half.

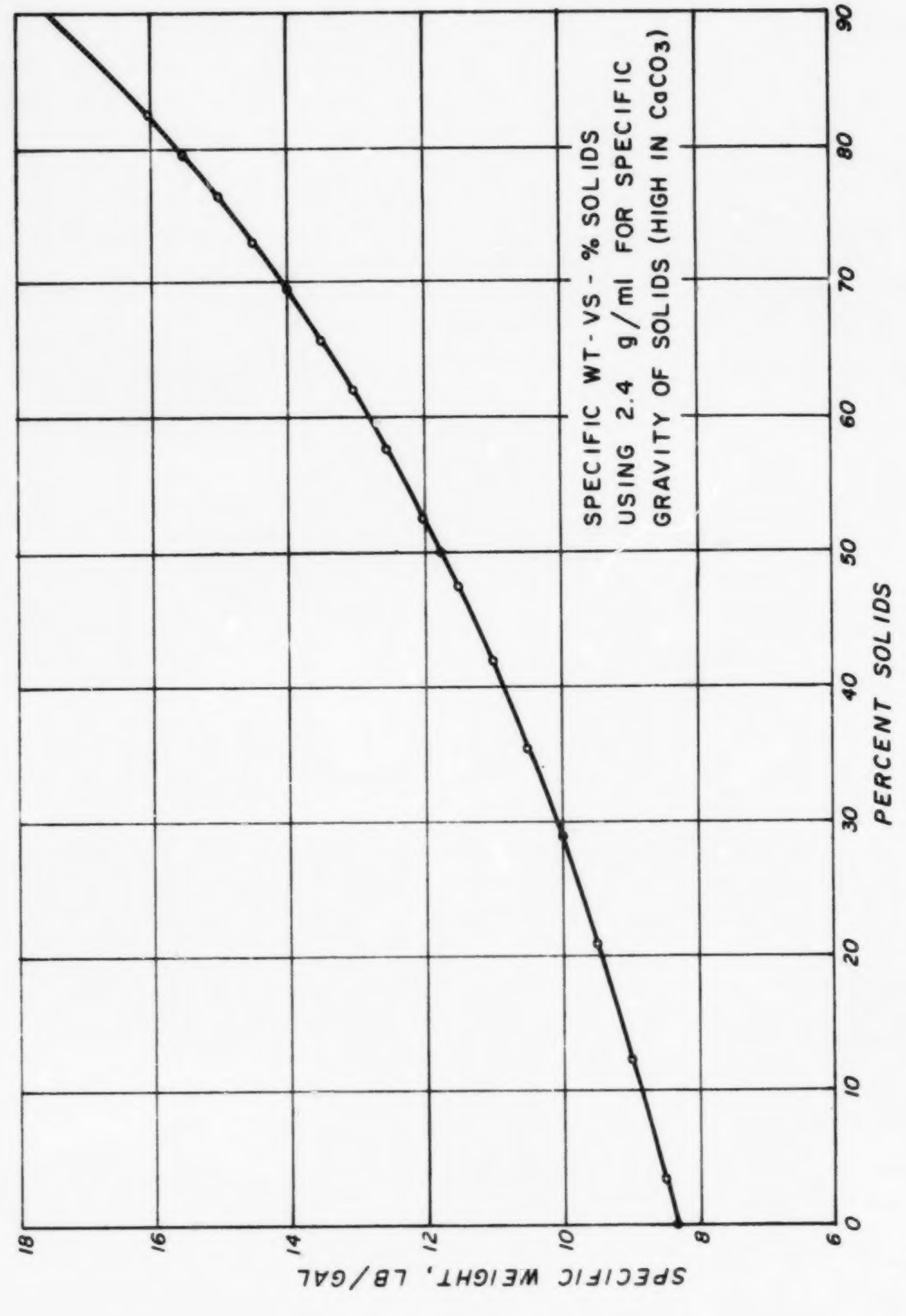


Figure 7-27 Relationship between solids concentration and specific weight

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SECTION VIII

LIME SLUDGE RECALCINATION AND WASTE SLUDGE INCINERATION

GENERAL CONSIDERATIONS

Lime recovery from chemical sludges has been practiced in the pulp and paper industry and in the water softening field[1] for many years. In wastewater treatment however, the practice is much more recent dating back to 1968 when the South Tahoe water reclamation plant began to successfully reclaim lime from the tertiary treatment sludge.[2]

The economics of lime recovery from wastewater sludges are quite different than for water softening sludges. In the latter case, since the softening reactions cause calcium hardness to precipitate as calcium carbonate, generally more lime is produced than is added for treatment. As a result, lime recovery operations in the water softening industry often show a profit.[1] On the other hand, due to process inefficiencies and losses, which will be explained later, only 50-70 percent recoveries of the required lime dose are usually possible from wastewater lime sludges. Consequently, new lime must be purchased to make up for the losses. Once steady state conditions are reached, the quantity of make up lime required can be expected to remain constant.

Lime recovery from wastewater sludge is attractive because recalcination, being a combustion process, can also be regarded as a method of sludge disposal. Therefore by recalcining the lime sludge, not only the spent chemical is reclaimed to be used again, but also the expensive problem of process solids disposal is greatly simplified at the same time.

In general, sludge incineration involves two steps, (a) drying and (b) combustion. In turn, the drying and combustion processes consist of the following phases: (1) raising the temperature of the feed sludge to 100 C (212 F), (2) evaporating water from the sludge, (3) increasing the water vapor and air temperature of the gas, (4) increasing the temperature of the dried sludge volatiles to the ignition point, and (5) combustion of the volatiles. The end products of combustion are water vapor, carbon dioxide, sulfur dioxide, nitrogen gas and inert ash.

Another important consideration in incineration processes is the required amount of combustion air. When any material burns, it combines with the oxygen in the air. The amount of air required can be theoretically calculated from the sludge composition.[3] This amount is called "theoretical air". In practice, however, it is necessary to supply more air than is theoretically required since it is not possible to distribute the air evenly over the burning bed of material. The amount of air supplied in addition to the theoretical air is called "excess air" and is usually given as a percentage of the theoretical air. So, burning with 100 percent excess air means supplying twice as much air as is theoretically necessary. The fundamental requirement is that enough air be admitted to the incinerator to ensure proper combustion of the sludge. If not enough air is admitted, the sludge will burn with a smoky flame, produce products of incomplete combustion such as carbon monoxide, and emit offensive odors. Insufficient air may also encourage formation of clinkers in certain types of incinerators. On the other hand, after the theoretically required air is supplied, the more excess air is admitted, the cooler the incinerator will become and the more auxiliary heat will be required to maintain combustion. Fig. 8-1 illustrates the relationship between auxiliary fuel and excess air.[4] Gas costs are rising and the fuel costs per ton can be proportionately increased over that shown in Fig. 8-1 to reflect local conditions.

LIME SLUDGE RECALCINATION

Recalcination of lime sludges is a process in which sludge is burned to decompose calcium carbonate to calcium oxide (lime) for reuse in treating more wastewater. The incinerator temperatures required to achieve this conversion are 871-982 C (1600-1800 F) and the decomposition is expressed by the following equation:

$$CaCO_3 \longrightarrow CaO + CO_2 \text{ (gas)}$$

Quantitatively this equation can be represented as a function of CO_2 concentration and temperature as shown in Fig. 8-2.[5] Since any incinerator will contain 10-20 percent CO_2 by volume it can be seen that active and energetic decomposition can be expected when the solids reach temperatures above 760-816 C (1400-1500 F). Any hydrated materials such as magnesium and iron hydroxides will decompose to their respective oxides well below these temperatures.

During the test work at the CCCSD's ATTF, it was found that the conversion efficiency of calcium carbonate was related to temperatures in the recalcining hearths of the multiple hearth furnace.[6] To obtain 95 percent lime recovery efficiency, a temperature of 932 C (1710 F) in the recalcining hearth was required. The carbon dioxide content was 13-17 percent, and Fig. 8-2 shows that the practical recalcining temperature is considerably greater than the theoretical value, because (a) a temperature difference is needed to transfer heat between the gas and the solids being recalcined and (b) the equilibrium data (Fig. 8-2) were obtained at long contact times and do not apply exactly in a practical circumstance where reaction time is not long.

Carbon dioxide liberated during combustion can be collected and used for pH adjustment, i.e., recarbonation, in the lime treatment system.

As indicated in Section VI, lime recovery is economically attractive in high lime applications since the additional benefits derived from higher lime doses can be justified when lime is to be recovered. At this range of pH (11-11.5), the precipitation of magnesium as magnesium hydroxide is practically complete and the calcined magnesium (MgO) does not react in water. Consequently, unless the lime sludge is classified to remove magnesium prior to incineration, the

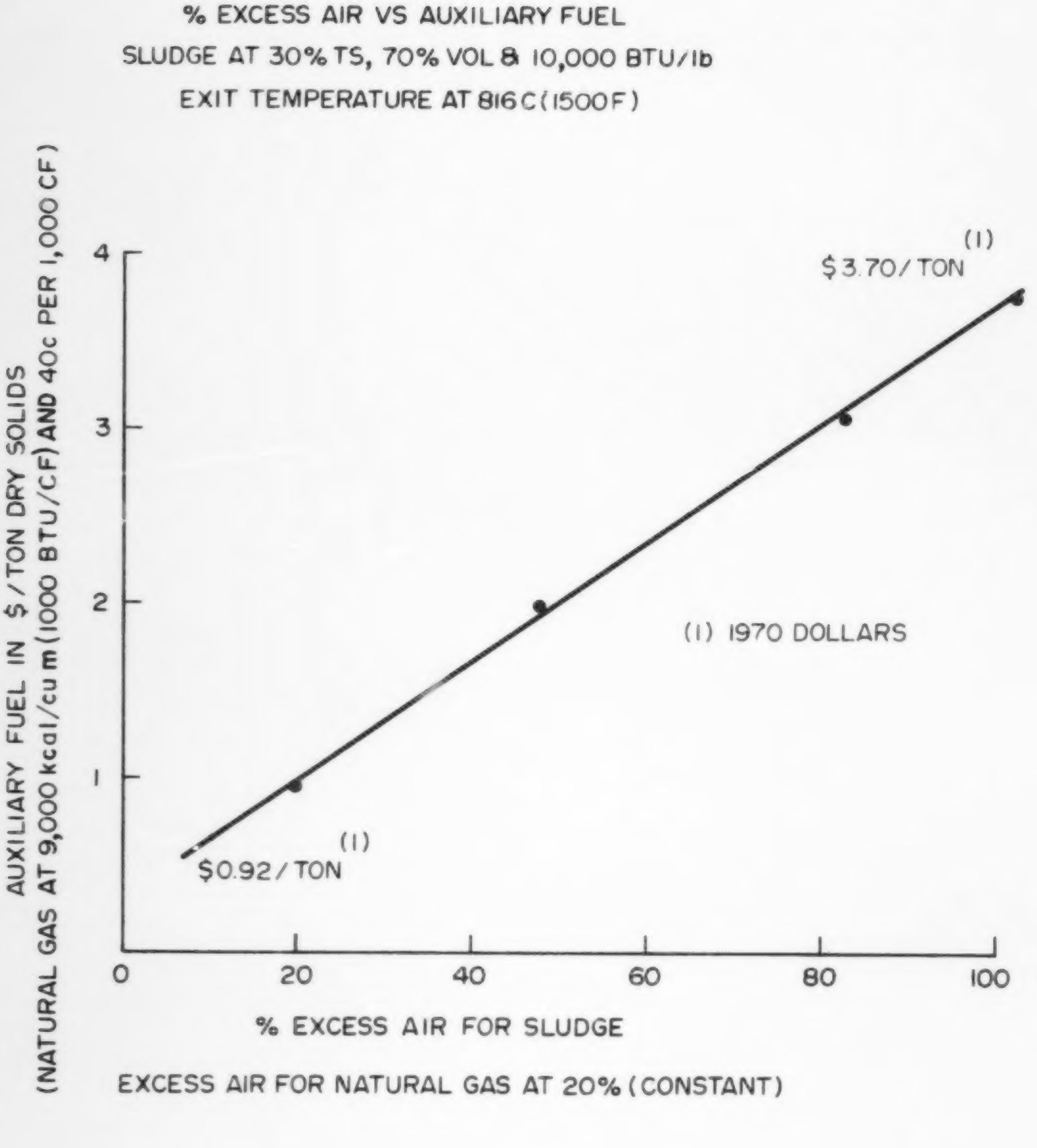


Figure 8-1 Effect of excess air on the cost of sludge incineration

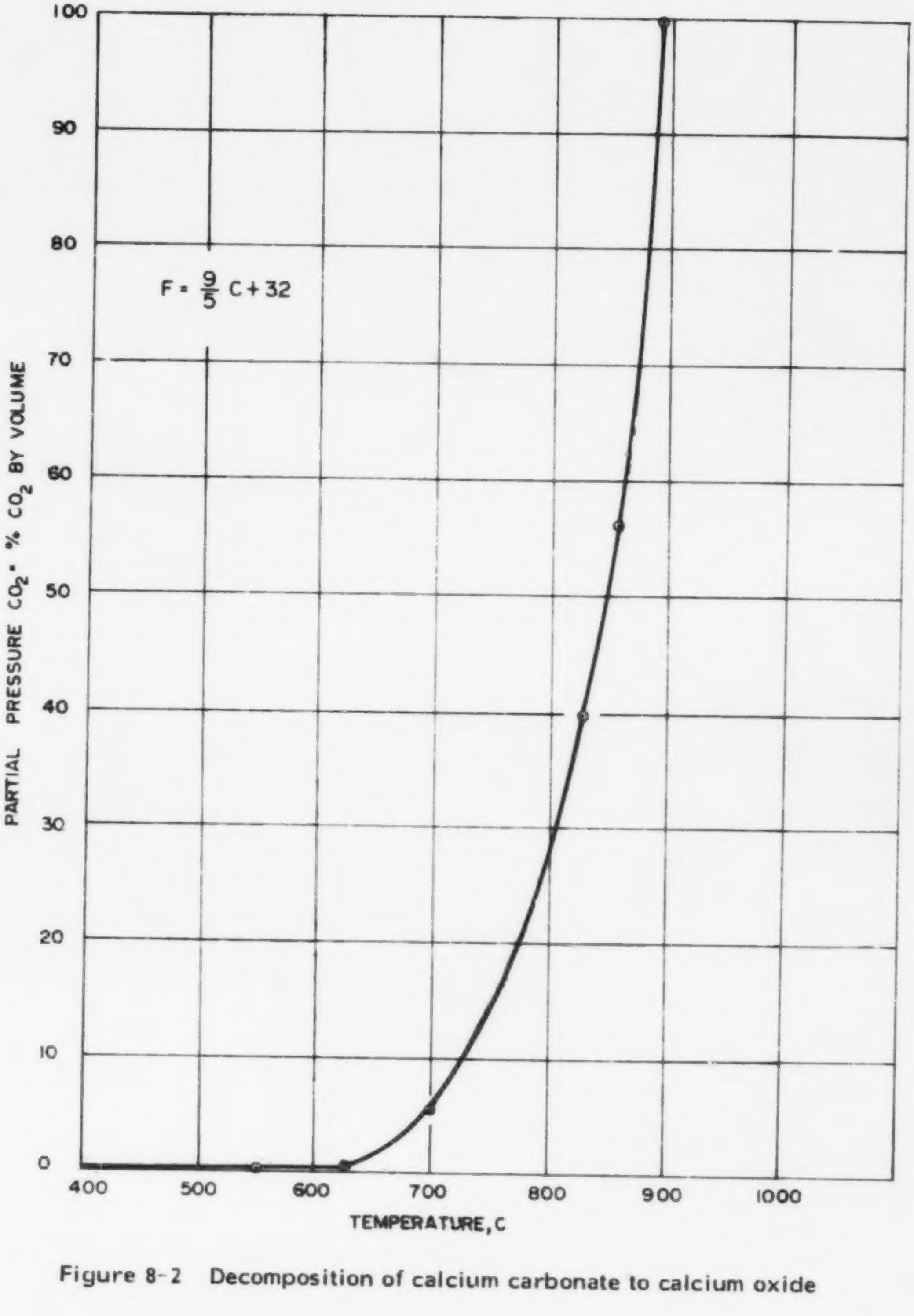


Figure 8-2 Decomposition of calcium carbonate to calcium oxide

recalcining process will render a product with a high percentage of unreactive magnesium oxide. By contrast, wet classification of the lime sludge is expected to reduce the proportion of magnesium oxide in the recalcined product to 5 percent or less by weight.[7] However, even after wet classification, other inerts will build up in the system because complete rejection of inerts is not achieved. Inerts which build up are magnesium, phosphorus, iron, silica and other compounds. As a result, the available lime in the recalcined product may be only 60 to 77 percent.[7,8]

Inerts buildup can also be controlled by continuously purging ("blowing down") a portion of the furnace product to equal the incremental increase in non-carbonate solids added to the lime sludge during precipitation.[9] Naturally, the blowdown also wastes a portion of the reclaimed calcium oxide so make up lime is required. Solid balances presented in Section X, Table 10-10, show that in a flow sheet without wet classification, 28 percent of the furnace product must be purged to approximate the amount of solids generated in a system that incorporates wet classification (Fig. 7-9). Also, at 28 percent ash blowdown, the makeup lime requirements are 55 percent of the overall requirements; in the flow sheet with wet classification, makeup lime accounts for only 38 percent of the total requirements. Thus, product purging is a wasteful means of controlling inerts as the overall recovery of lime in the process is reduced.

Another means for increasing the effectiveness of purging is to use dry classification. It may be used alone or in conjunction with wet classification. As described later in this section, dry classification uses particle size selection to preferentially reject silica from the system.

Three types of recalcining plants are used to recover lime from process sludges: rotary kilns, fluidized bed reactors and multiple hearth furnaces. The first two types have been used extensively in industrial and water softening application. The multiple hearth furnace seems to have taken the lead in lime recovery applications from wastewater sludges.

Multiple Hearth Furnaces

Multiple hearth furnaces (MHF) are used at South Tahoe, California,[2] Colorado Springs, Colorado and Piscataway, Maryland for full scale recovery of lime from tertiary treatment wastewater sludge. Four additional installations are under different stages of construction in the U.S. and several more are in the planning and design phases.[10] The MHF was initially developed for use in the mining industry for roasting ores. It has been widely used in municipal applications for disposal of both primary and biological sludges for over 40 years.[11] Other solid products of wastewater treatment including grit, scum and screenings have also been incinerated in the MHF. The popularity of multiple hearth units can be attributed to their simple design and flexibility of operation under varying feed rates.[4]

The multiple hearth furnace is a circular structural steel shell lined with refractory brick, and the interior is divided into separate compartments (i.e., hearths) by horizontal brick arches. An air cooled central shaft supports the cantilevered rabble arms (two or four) provided on each hearth. Revolving rabble arms move the sludge from hearth to hearth alternately inwards and outwards so the sludge travels radially the full width of each hearth before dropping to the next one. This travelling pattern has been used to name the two hearth types. Those in which sludge enters near the periphery and exits through openings around the center shaft are called "in-feed" hearths. Those in which sludge is rabbled from the center towards the hearth periphery, where the drop holes are located, are called "out-feed" hearths. Fig. 8-3 shows a typical MHF.

As the material passes down through the furnace, three distinct zones are established. The upper hearths form a drying and gas cooling zone. Here, vaporization of some free moisture occurs as well as cooling of exhaust gases by transfer of heat from the hot gases to the sludge. Intermediate hearths form a high temperature burning zone, or combustion zone, where all volatile gases and solids are burned. Combustion of most of the total fixed carbon takes place on the lowest hearth of the combustion zone. The bottom hearths of the furnace function as a cooling and air-preheating zone where ash is cooled by giving up heat to the returned shaft cooling air. The relative location of the zones will tend to shift as the result of changes in the quality and quantity of the feed, i.e., the sludge feed rate and the moisture content of the cake. If there is enough combustible matter in the sludge cake, sufficient heat will be liberated by the burning solids to drive off the moisture in the sludge cake on the upper hearths to the point where this material itself will ignite as it reaches the combustion zone. Thus, the incineration process may be self-sustaining (autogenous combustion).

A comprehensive thermal analysis of combustion in the MHF is given in Reference 11. In general, sludge has to be 25-30 percent solids with a volatile solids content of 70 percent (and no solids to be calcined) for autogenous combustion. If afterburning is required to control air pollution (see Section IX), auxiliary fuel is necessary to reach afterburning temperatures, although autogenous combustion could still occur in the burning hearths.

A temperature profile across a typical sludge furnace is given in Table 8-1.[12] For design purposes, excess air for combustion of volatiles in the sludge is usually set at 50-75 percent. Normal operation conditions may show a lower percentage of excess air.[12]

For a given solids load to a MHF, lime recalcination requires additional hearths over the number normally required for sludge combustion. In the CCCSD water reclamation plant,[13] the furnaces will have ten hearths (an eleventh hearth will be used as an afterburner). Approximately two hearths are required to dry the feed, two hearths to preheat the feed to calcining temperature (899 C (1650 F) solids temperature or about 1010 C (1850 F) gas temperature), four hearths to get complete calcination and two hearths to cool the product.[14] Excess air for sludge recalcination is normally set at 100 percent. Table 8-2 gives the anticipated temperature profile for the CCCSD lime furnaces.

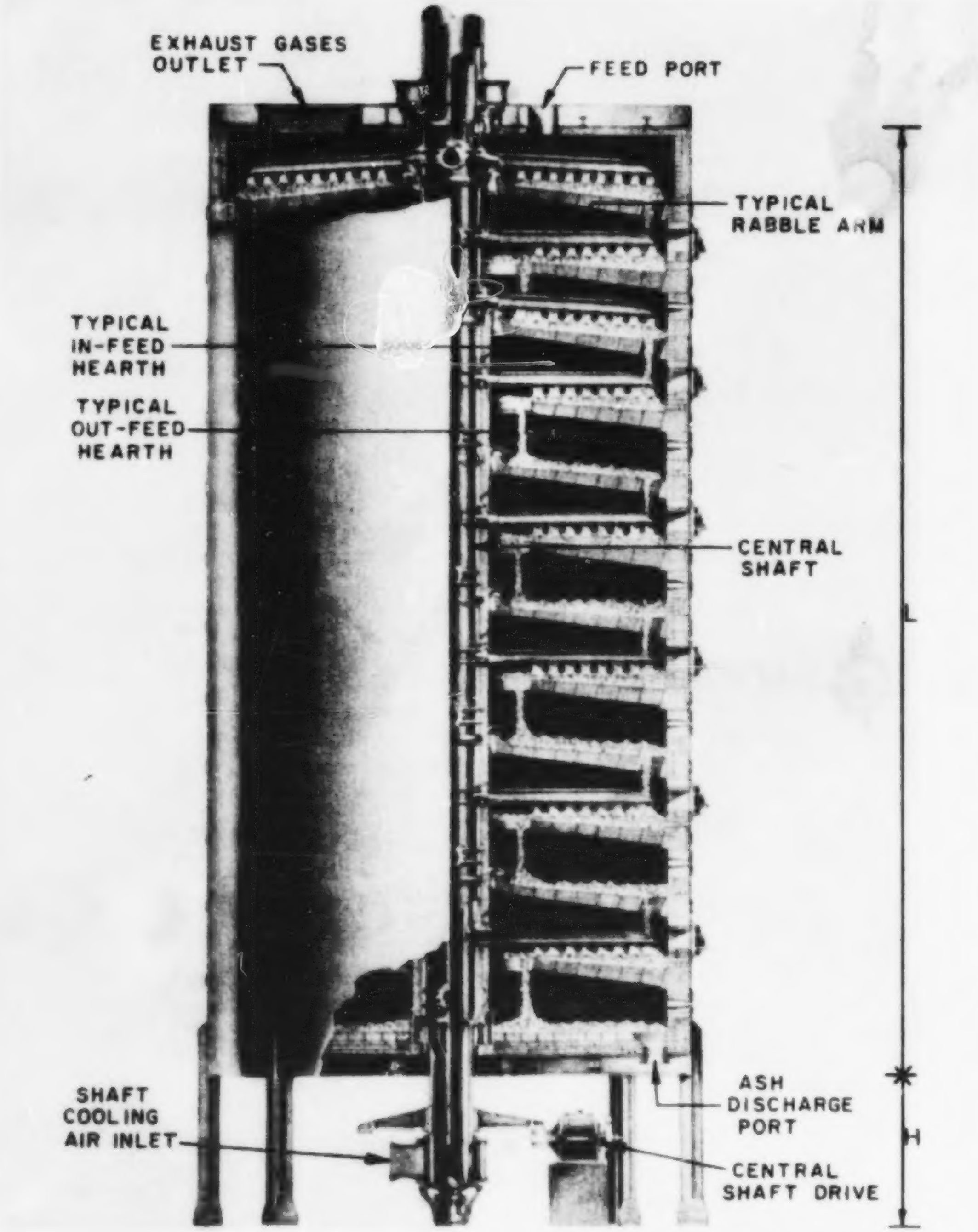

EXHAUST GASES OUTLET
FEED PORT
TYPICAL RABBLE ARM
TYPICAL IN-FEED HEARTH
TYPICAL OUT-FEED HEARTH
CENTRAL SHAFT
L
ASH DISCHARGE PORT
H
SHAFT COOLING AIR INLET
CENTRAL SHAFT DRIVE

Figure 8-3 Typical multiple hearth furnace (courtesy of BSP Division-Envirotech Systems, Inc.)

Table 8-1. TYPICAL TEMPERATURE PROFILE IN SIX HEARTH FURNACE

Hearth No.	Temperature	
	C	F
1 (Top)	427	800
2	649	1,200
3	899	1,650
4	788	1,450
5	649	1,200
6 (Bottom)	149	300

Table 8-2. TEMPERATURE PROFILE IN LIME RECALCINATION FURNACE FOR CCCSD

Hearth No.	Temperature	
	C	F
1 (Top)	760[a]	1,400[a]
2[b]	427	800
3	677	1,250
4	899	1,650
5	1,010	1,850[c]
6	1,010	1,850[c]
7	1,010	1,850[c]
8	1,010	1,850[c]
9	1,010	1,850[c]
10	677	1,250
11 (Bottom)	399	750

[a] Top hearth used as afterburner

[b] Feed hearth

[c] Test work indicates that a temperature as low as 932 C (1,710 F) may be adequate.

The MHF is sized based on solids loading per unit of hearth surface area. Sizing is influenced by the characteristics of the sludge cake, including moisture, volatile solids, inerts content, and calorific value. 34 to 59 kg of wet sludge per hour per square meter of hearth area (7-12 lb/hr/sq ft) is the range of loading rates commonly used in determining the required hearth area.[12] Rates for recalcining furnaces are generally in the low end of this range. The somewhat lengthy procedure used to size a MHF has been greatly simplified by the development of digital computer routines.[11,12]

The modular construction of MHFs allows their use in a wide range of solids loadings. Typically, additional capacity is obtained by increasing the furnace diameter, increasing the number of hearths, or both. Table 8-3 shows the standard furnace sizes offered by a large manufacturer of the MHF.[12] The same manufacturer has developed a "Plural Purpose" furnace (a patented application).[15] This concept permits the use of a single unit for both lime recalcination and organic sludge incineration (Fig. 7-8). Scum, grit and screenings can also be burned together with the lime and organic sludges. The reclaimed lime is separated from the inerts by dry classification techniques.[12] Dry classification will be covered in detail later in this section.

Fluidized Bed Reactors

Fluidized bed reactors (FBR) are the type of recalciners most commonly used to recover lime from water softening sludges.[1] The FBR is also used in the pulp and paper field and in other industrial applications such as ore roasting, calcination of phosphate rock and limestone, etc. In wastewater treatment, fluidized bed techniques were first applied in Lynnwood, Washington in 1963 to burn both raw sludge and scum.[16] The first full-scale application of a FBR in lime recalcination from wastewater sludge was started in Elkhart, Indiana in 1974.[17]

Basically, a FBR consists of a vertical steel shell internally divided into horizontal compartments. In general, the number of compartments depends on the type of material burned in the reactor and its mode of operation. A layer or "bed" of the granular material (either lime pellets or sand) is placed at the perforated bottom of a compartment. As preheated air flows into the burning section, its upward velocity suspends the solid particles and the bed expands. This mixture of solids and gas is said to be fluidized since it behaves not unlike a true liquid.[18] The physical appearance of the fluidized bed has been described as similar to boiling water due to the intense mixing between air and bed material. Combustion of either fuel or sludge takes place within this bed and is completely dependent upon this intense mixing action.

Two distinct types of fluid bed systems have been applied to lime recovery from waste calcium carbonate sludges. The bed in one type of unit (Fig. 8-4) consists of pellets of recalcined lime. In the other type of unit, sand is used to form the fluid bed.

Table 8-3. STANDARD MULTIPLE HEARTH FURNACE SIZES (COURTEST OF BSP DIVISION-ENVIROTECH SYSTEMS, INC.)

I.D.	O.D. for wall thickness of			Col. height[a]	Square feet of effective hearth area and "normal" shell height[b]											
					Hearths											
	6"	9"	13 1/2"		1	2	3	4	5	6	7	8	9	10	11	12
13"	18" @ 2 1/2"			1'	1	2 1/4 1'8"	2 1/4	3 3'4"								
20"	30" @ 5"			1'3"	2	4 2'0"	6	8 4'0"	10	12 6'0"						
30"	3' @ 3"	44" @ 7"		1 1/2"	4	8 2'2"	12	16 4'4"	20	24 6'	28	32 7'8"	36	40 9'4"		
39"	4'3"	4'9"	4'6"	2 1/2"	7	14 3'6"	19	28 6'	32	37 8'6"	42	48 11'0"	54	61 13'6"		
54"	5'6"	6'	6'9"	4'	15	31 4'2"	42	63 7'4"	74	85 10'6"	98	112 13'8"	126	140 16'10"		
5 1/2'	6'6"	7'	7'9"	4'	24	47 4'8"	63	94 8'3"	110	125 11'10"	145	166 15'5"	187	208 19'0"		
7'	8'0"	8'6"	9'3"	5'	32	65 6'3"	96	130 10'10"	161	193 15'5"	225	256 20'0"	288	319 24'7"	351	383
8 1/2"	9'6"	10'	19'9"	6 1/2'	47	94 6'3"	138	188 10'8"	235	276 15'1"	323	364 19'5"	411	452 23'10"	510	560
10 1/2'	11'6"	12'	12'9"	6 1/2"	80	148 8'4"	227	295 14'0"	374	442 19'8"	521	589 24'4"	668	736 31'0"	815	883 36'8"
12'	13'0"	13'6"	14'3"	6 1/2"	97	195 6'9"	287	390 11'8"	487	575 16'7"	672	760 21'5"	857	944 26'4"	1,041	1,128 31'2"
14 1/2'	15'6"	16'	16'9"	7'	143	286 8'0"	422	573 13'2"	716	845 18'7"	988	1,117 24'1"	1,260	1,400 29'6"	1,540	1,675 35'0"
16 1/2'	17'6"	18'	18'9"	7'	181	363 8'4"	534	727 14'3"	908	1,068 20'2"	1,249	1,410 26'0"	1,591	1,752 31'11"	1,933	2,090 37'9"
18'	19'0"	19'6"	20'3"	8'	215	438 8'4"	634	863 14'4"	1,078	1,268 20'2"	1,483	1,660 26'1"	1,875	2,060 31'11"	2,275	2,464 37'10"
20'	21'0"	21'6"	22'3"	8'	269	538 9'6"	790	1,077 16'1"	1,346	1,580 22'9"	1,849	2,084 29'6	2,350	2,600 36'2"	2,860	3,120 42'11"
23 1/2'	24'6"	25	25'9"	8'	382	764 11'4"	1,145	1,528 18'9"	1,909	2,292 26'2"	2,674	3,056 33'7"	3,438	3,818 41'	4,200	4,584 48'5"
26'	27'0"	27'6"	28'3"	8'	463	926 12'7"	1,389	1,852 20'9"	2,315	2,778 28'10"	3,241	3,704 36'11"	4,167	4,630 45'	5,093	5,556 53'1"
28'	29'0"	29'6"	30'3"	8'	610	1,155 13'	1,690	2,235 22'	2,770	3,315 31'	3,850	4,395 40'	4,930	5,475 49'	6,010	6,555 58'

[a] Dimension H in Fig. 8-3.
[b] Dimension L in Fig. 8-3.

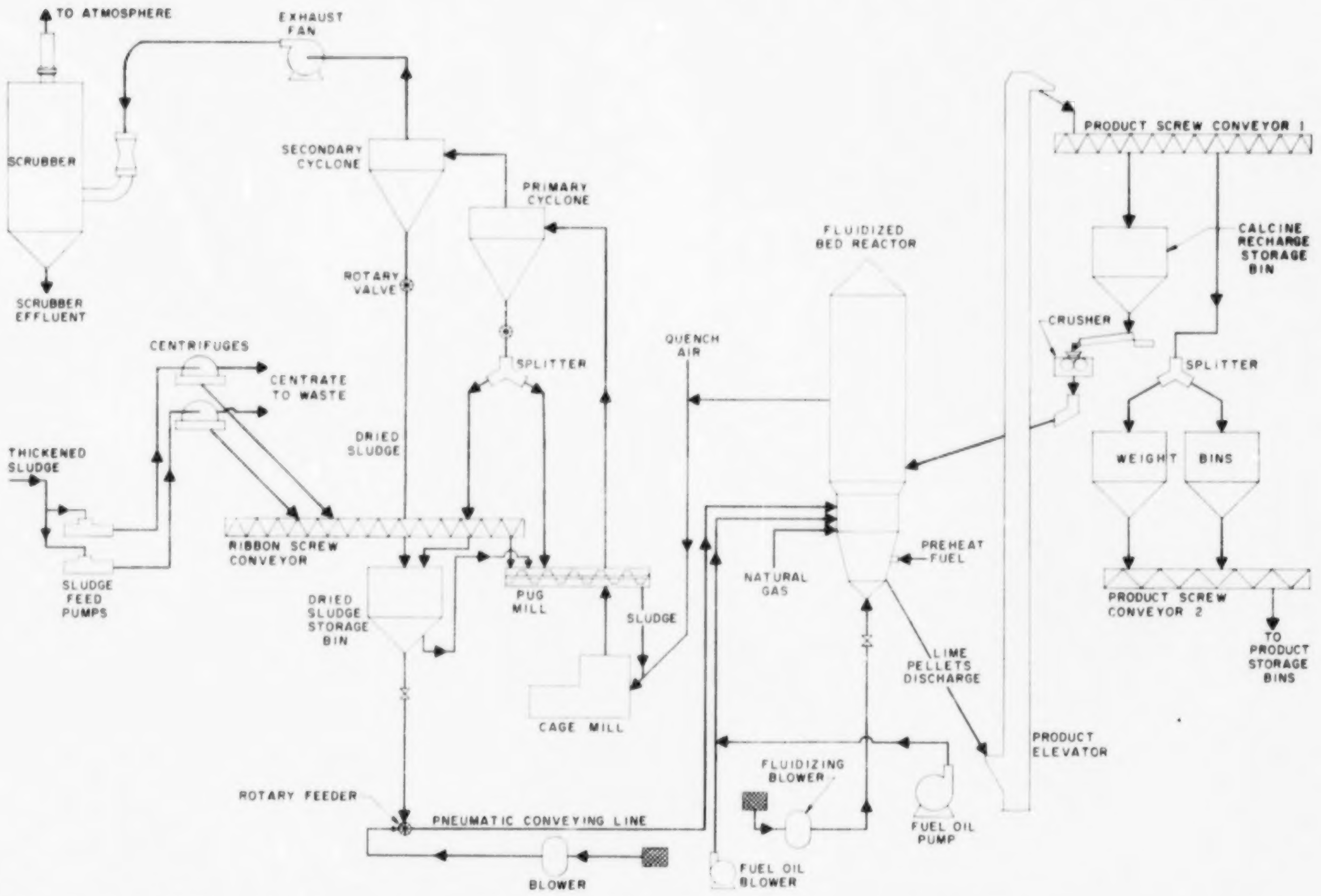

TO ATMOSPHERE
EXHAUST FAN
SCRUBBER
SCRUBBER EFFLUENT
SECONDARY CYCLONE
PRIMARY CYCLONE
ROTARY VALVE
CENTRIFUGES
CENTRATE TO WASTE
SPLITTER
QUENCH AIR
FLUIDIZED BED REACTOR
PRODUCT SCREW CONVEYOR 1
CALCINE RECHARGE STORAGE BIN
CRUSHER
SPLITTER
WEIGHT BINS
THICKENED SLUDGE
DRIED SLUDGE
RIBBON SCREW CONVEYOR
SLUDGE FEED PUMPS
DRIED SLUDGE STORAGE BIN
PUG MILL
SLUDGE
CAGE MILL
NATURAL GAS
PREHEAT FUEL
LIME PELLETS DISCHARGE
PRODUCT SCREW CONVEYOR 2
TO PRODUCT STORAGE BINS
PRODUCT ELEVATOR
FLUIDIZING BLOWER
FUEL OIL PUMP
ROTARY FEEDER
PNEUMATIC CONVEYING LINE
BLOWER
FUEL OIL BLOWER

Figure 8-4 Schematic diagram of a pellet bed calcining system (courtesy of Dorr-Oliver Incorporated)

A wide range of capacities can be accommodated with the FBR. Lamb[17] has reported 18 lime mud reburning installations as of March 1972, ranging in capacity between four and 220 tons of lime per day. The maximum capacity of a single fluidized bed calciner is estimated at 250 tons of lime per day. Sand bed reactors have been built from four to 20 ft in internal diameter for the incineration of wastewater sludges.

The FBR is sized on the basis of the gas velocity required to fluidize the bed material. For pellet bed type units, velocities of approximately 1.8 m/sec (6 ft/sec) are usual whereas for sand bed units, the superficial reactor velocity is about 0.6-0.9 m/sec (2-3 ft/sec). Any given bed material will fluidize only over a limited range of gas velocities and this fact imposes a limitation on the flexibility of the FBR to accommodate variations in capacity much beyond ± 20 percent of design without serious losses in efficiency. In a practical sense the capacity in terms of tons of sludge per square foot per hour is largely governed by its moisture content and its calcium carbonate content--the two principal contributors to heat requirements.

An attractive feature of the FBR is its ability to restart quickly on shut down. The fluidized bed acts like a large heat reservoir. Normally a hot sand bed will lose only 0.5 C per hour during down time.[19] The FBR can also build up temperature rapidly due to the high heat transfer properties of the gas-bed mixture. Heat transfer rates for an FBR bed are some 5 to 25 times that of gas alone.[19] As a result of the heat properties of a FBR, shut down-start up cycles are much shorter than for a MHF.

Pellet Bed Units -

In the fluidized bed system that has been used to recover lime from water softening and pulp and paper mill sludges, the pellet bed reactor is only the calcination and cooling part of the lime recovery system. Essential to the operation of the system are some related processes which will now be described. After passing through a thickening-dewatering stage (see Fig. 8-4 and Section VII), sludge cake is mixed with predried calcium carbonate in a paddle type mixer. Mixing with a dry product, required because dewatered cake is sticky and difficult to transport, results in the formation of easily moveable lumps. From the paddle mixer solids are discharged into a cage mill. Here, the lumps are broken up and the solids are exposed to a stream of exhaust gases from the reactor. The solid particles are rapidly dried by the hot gases and carried to a cyclone where the dried carbonate is separated from the gas stream. A portion of the material collected in the cyclone is returned to the paddle mixer to condition dewatered cake and the remainder is transferred to a dried sludge storage bin. From the storage bin, a pneumatic conveyor feeds the dried sludge to the burning compartment of the FBR. Fuel, either gas or oil, is also injected into this compartment. Once in the burning compartment, where temperatures are maintained at 816-927 C (1500-1700 F), the calcium carbonate particles are rapidly converted to calcium oxide. The CaO particles agglomerate into larger particles, aided by the violent mixing in the bed. To promote pellet formation and to control its size, an agglomerating agent (soda ash) is normally introduced along with the feed sludge. Crushed lime pellets are added as seed particles. Lime pellets are discharged from the calcining zone to the cooling section through an internal transfer pipe. In the cooling compartment hot lime is fluidized with incoming air which lowers the product temperature to 227 C (440 F) and in turn, preheats the air to that same temperature before entering the calcining section. Cooled, dust free pellets are continuously transferred from the cooling compartment to a storage bin through a bucket elevator. Fig. 8-5 shows a cross section of a typical fluidized bed calciner.

One attractive feature of the pellet bed unit is the heat recovery that is integral to the system. Hot off-gases from the reactor are used for flash drying of the cake fed to the system. Discharge gas temperature from the system usually is only 135 to 149 C (275 to 300 F),[20,21] compared to the usual 427 C (800 F) in a MHF (without after burning) or 816 C (1500 F) in a sand bed FBR. As a consequence, the pellet bed unit requires from one-half to one-third the fuel per ton of CaO of a sand bed FBR.[22] The excess air required for the burning of either or both the fuel and sludge is only 20-30 percent as opposed to 70-100 percent in the MHF.

Up to the present time, the pellet bed FBR has been applied strictly to paper pulp mill and water softening applications. The process will be applied to a tertiary treatment lime sludge in a plant currently under construction in Virginia.[17]

The chief U.S. manufacturer of the unit, Dorr-Oliver Incorporated, is cautious about the application of the pellet bed FBR to lime sludges generated in the primary sedimentation tank. The main concerns expressed are related to whether excessive dusting would occur in the reactor due to the increased level of inerts in a cake generated by primary processes as compared to tertiary processes. In one water softening application, granular silica in the raw influent increased dust losses from the normal 15 percent loss up to 25 percent. It was concluded that if the pellet bed FBR is going to be applied to lime recovery in raw wastewater treatment, further research on the control of pelletization in the process is required.[22] The same note of caution is expressed by Krause.[23] He noted that even sludges from similar application, but different locations, differed in their behavior in the pellet bed FBR. A considerable period must be allowed after start up for fine tuning and modification of the system to allow its full performance to be obtained.

When the pellet bed reactor is applied to wastewater sludges, attention must also be given to odor control in the unit. During incineration of organic sludges, it is often contended that the combustion zone must be held at 649-816 C (1200 to 1500 F) for effective destruction of odorous substances (see Section IX). While it is true that the pellet bed FBR operates at 816 C (1500 F) in the calcining zone, the hot off-gases are used to dry the cake in a cage mill. As a result of the predrying of the lime cake before it is fed to the reactor, the off gas temperature ahead of the wet scrubber is in the range of 135 to 149 C (175 to 300 F). Consequently, odors may be created in the drying zone from volatilization of organics. Afterburning of the off-gases may be required if the pellet bed FBR is applied to lime recalcination of raw wastewater sludge. Afterburning will naturally reduce its overall fuel efficiency.

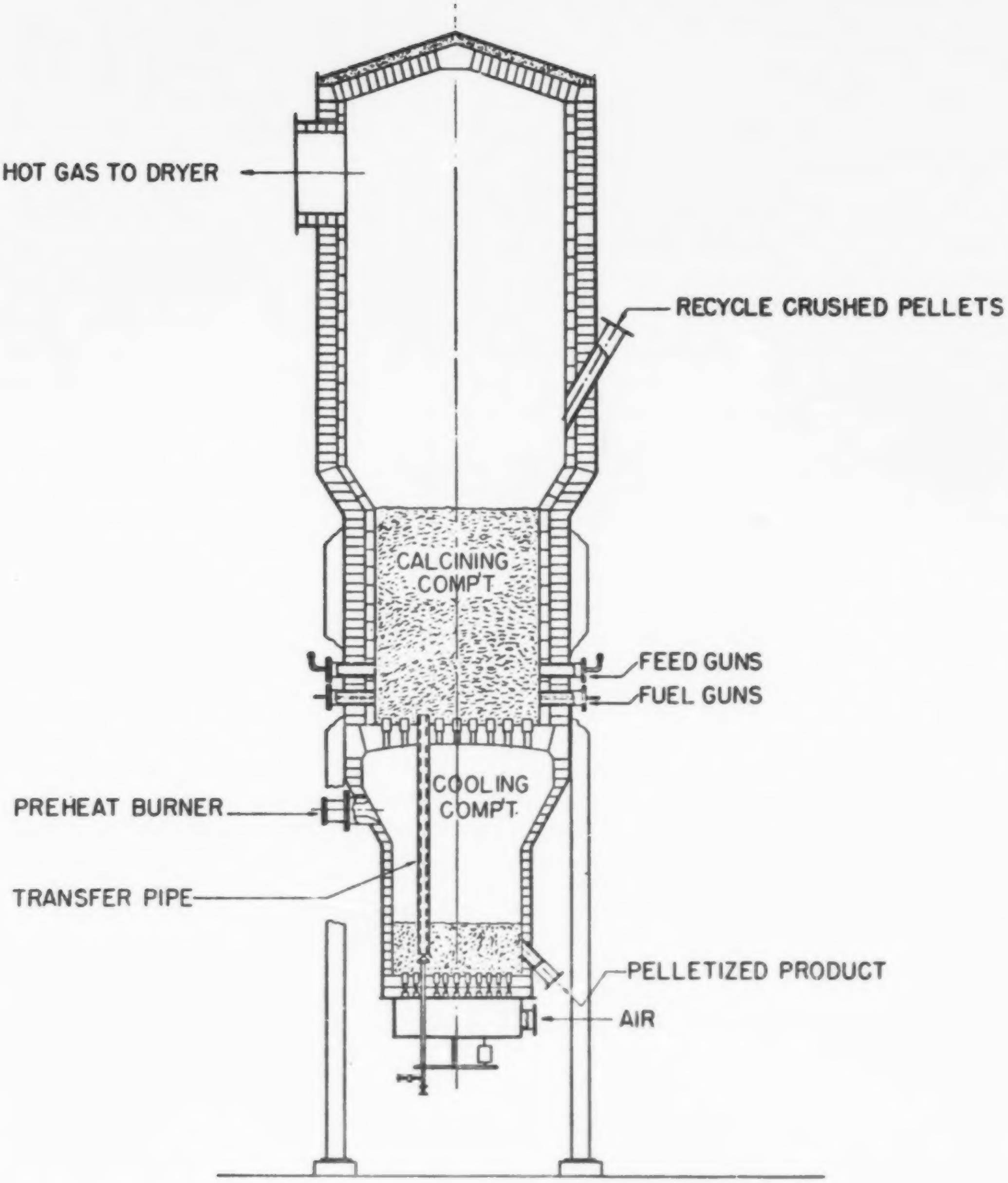

HOT GAS TO DRYER
RECYCLE CRUSHED PELLETS
CALCINING COMP'T
FEED GUNS
FUEL GUNS
COOLING COMP'T
PREHEAT BURNER
TRANSFER PIPE
PELLETIZED PRODUCT
AIR

Figure 8-5 Typical fluidized bed calciner

(courtesy of Dorr-Oliver Incorporated)

Due to lower levels of organic solids in tertiary lime sludges, afterburning may not be required for tertiary treatment applications.

Sand Bed Units -

Originally, the sand bed FBR was developed to incinerate sludges from both primary and biological treatment. It has since been applied to lime sludges as well. Differences from the basic pellet bed unit are the elimination of the sludge drying step, the dewatered cake being fed directly to the burning zone of the FBR by a positive displacement pump or a screw conveyor; and the replacement of the bed of lime pellets used with water softening and paper pulp sludges with a bed of graded silica sand. Fig. 8-6 shows the modified flow sheet for applications involving lime treatment of raw wastewater.

In the modified FBR for lime recalcination, pellet formation is inhibited and all the calcium oxide particles are carried by the exhaust gases to a hot cyclone where CaO is separated from the gas stream. From the cyclonic collector, lime discharges into a quenching tank, where it is slurried by the cooling water and then discharged to a collection tank. Slaking of the lime to $Ca(OH)_2$ takes place in this tank. In this tank, which also receives water discharged from the wet scrubber and a conditioning ash slurry, the lime slurry is further diluted and then pumped to an ash thickener. In the process of dilution, the lime is dissolved, resulting in a nearly saturated solution of calcium hydroxide and leaving the other constituents in suspension. Albertson[24] has reported that the separation of the suspended matter from the calcium hydroxide solution in the thickener is extremely rapid. Overflow rates of 100 to 120 cu m/day/sq m (2500 to 3000 gpd/sq ft) may be possible. Supernatant from the thickener, containing the calcium hydroxide, is then returned to the primary clarifier to recycle the lime. Thickener underflow is pumped to a dewatering step prior to final ash disposal.

At the time this manual was being written, no full-scale operational data were available on the modified FBR flow sheet shown in Fig. 8-6. Albertson and Sherwood[25] have reported the results of lime recovery tests conducted both in a 12-inch, laboratory scale reactor and in a 4-ft FBR used to incinerate organic sludge. In these tests lime sludge, obtained during bench scale studies of lime precipitation, was mixed with centrifuged organic cake and the mixture was fed to the reactor. Bed temperature was maintained at 871 C (1600 F). The combustion gases then passed through a cyclone separator and a wet scrubber. Laboratory analysis of the solids in the cyclone underflow showed that 79.6-90 percent available lime was captured in the unit.

Experience at Holland, Michigan - As mentioned before, there is no information available on full-scale operation of a sand bed-type FBR on wastewater sludges. The closest operation similar to lime recalcination is the FBR in operation at Holland, Michigan. At Holland, the FBR is used for sludge disposal for a low lime treatment plant rather than for lime recalcination. As a result, it does not have the hot cyclone and recovery system shown in Fig. 8-6. Nonetheless, the furnace is operated at 816 C (1500 F).[26] This operating

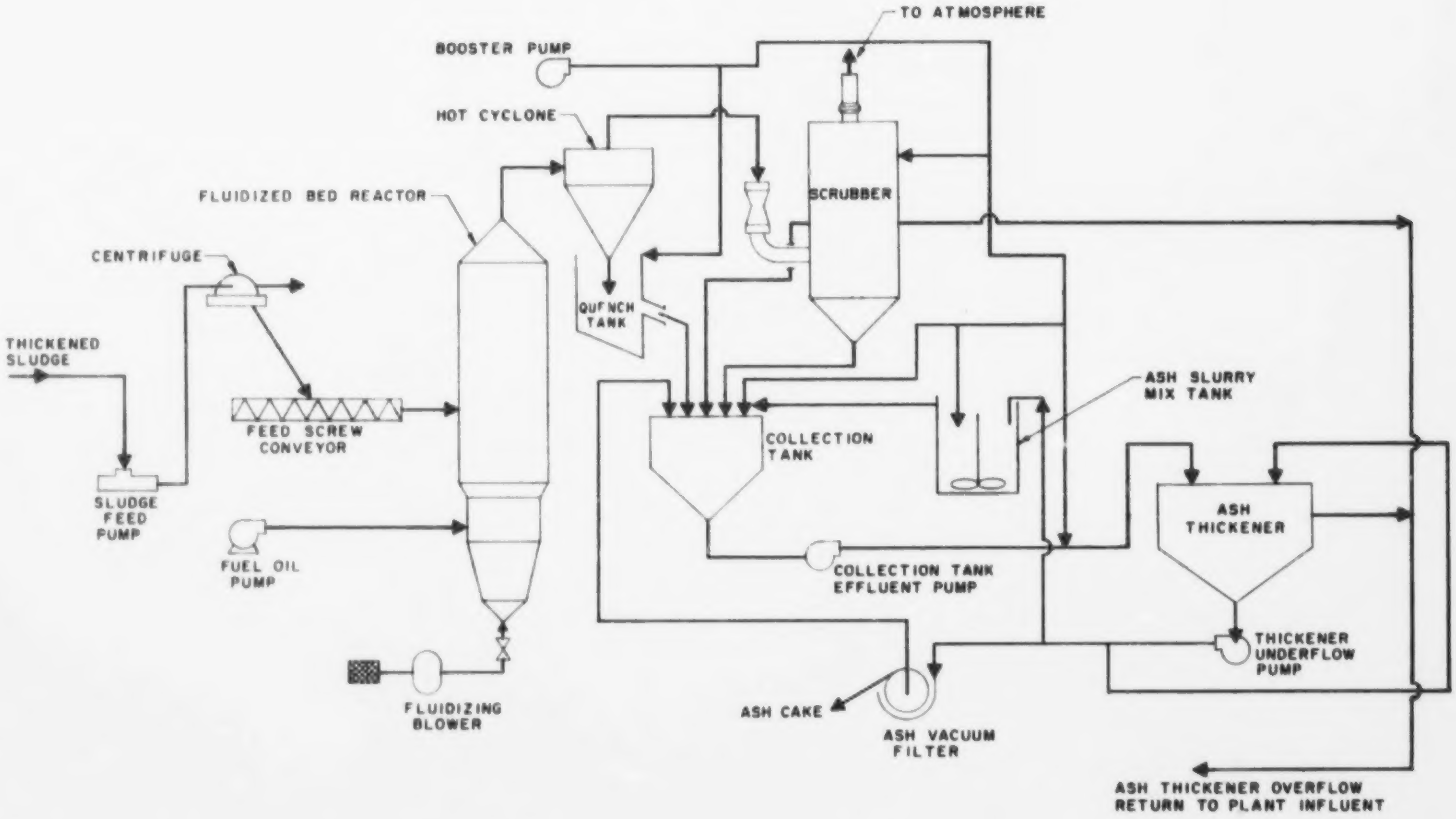

TO ATMOSPHERE
BOOSTER PUMP
HOT CYCLONE
FLUIDIZED BED REACTOR
CENTRIFUGE
THICKENED SLUDGE
SCRUBBER
QUENCH TANK
FEED SCREW CONVEYOR
SLUDGE FEED PUMP
FUEL OIL PUMP
COLLECTION TANK
ASH SLURRY MIX TANK
ASH THICKENER
COLLECTION TANK EFFLUENT PUMP
THICKENER UNDERFLOW PUMP
FLUIDIZING BLOWER
ASH CAKE
ASH VACUUM FILTER
ASH THICKENER OVERFLOW RETURN TO PLANT INFLUENT

Figure 8-6 Schematic diagram of a sand bed calcining system

(courtesy of Dorr-Oliver Incorporated)

temperature is sufficient for recalcination in a FBR. Certain operating experiences with this unit are worthy of discussion.

The FBR at Holland is a 4 m (13 ft) ID unit with a 1.5 m (60-inch) expanded bed. A total of 14 burners are provided. Normally, a screw conveyor is used to feed centrifuge cake. In cases where the centrifuges are down, thickened slurry may be fed through four feed ports using a Moyno pump. The unit has considerable overload capacity. It has been fed at 725 kg/hr (1600 lb/hr) without difficulty while its design is for 408 kg/hr (900 lb/hr).[26]

The current operating problem is that material is building up in the venturi scrubber causing high head losses in the gas discharge from the unit.[26] It is likely that calcium oxide is slaking in the scrubber, causing a deposit to form, much as occurs in a lime slaker. This condition requires at least semiannual maintenance.

Some pelletization has occurred on the sand bed particles, and bed material must be blown down to hold a constant bed volume in the system. Martin[26] stated that a volume equal to the bed volume has been blown down in approximately a seven-month period. After this initial blowdown, the sand particles seemed to have reached a maximum size and no further removal has been found necessary.[27] It has been found that 40 to 50 percent of the bed is calcium oxide. If pelletization occurs in a sand bed FBR, it defeats the intended mode of operation of the unit for recalcination, since product is removed from the effluent gases rather than from the bed. Dorr-Oliver states that pelletization has not occurred in a recalcining application where the sludge contains calcium carbonate from a tannery waste treatment plant. It is felt that the occurrence of unintentional pellet formation is affected by the type of inerts in the waste sludge, which may be unique in each application.[22] Further research on pelletization is required to define the conditions necessary for its control in the sand bed FBR before it can be applied with certainty to wastewater lime sludges.

Rotary Kiln Calciners

Until 1963, when the first fluidized bed reactor was installed at S.D. Warren Co. in Muskegon, Michigan,[20] the rotary kiln calciner (RKC) was the conventional method to recover lime in the pulp and paper mill industry. Rotary kilns have also been successfully used to reclaim lime from water softening sludges.[1] To date, no attempts have been made to apply the RKC to the recovery of lime from wastewater sludges.

A typical RKC consists of a long rotating steel shell lined with a refractory material. The shell is slightly inclined to facilitate movement of sludge along the kiln. Dewatered lime sludge is fed and off-gases exhausted at the upper end of the shell. This section is provided with a heat recovery chain to facilitate the exchange of heat between the sludge cake and the hot exhaust gases. Sludge is dried in this end of the RKC. After a residence time of one and a half hours and before being discharged at the lower, or firing end of the shell, sludge is nodulized (i.e., agglomerated in round-shape lumps) and converted to calcium oxide in the calcining zone. From the rotary shell, the product enters a peripheral tube cooler from which it is mechanically transferred to storage.

The temperature of the calcining zone is maintained at approximately 1093 C (2000 F), considerably higher than the theoretical temperatures required for recalcination. Temperatures as high as 1371 C (2500 F) have been used in some applications. Exhaust gases are emitted at 204 C (400 F). In the integral tube cooler, recalcined lime is cooled to approximately 316 C (600 F). The RKC requires higher temperatures than the MHF or FBR because the particle size of calcium carbonate in the rotary kiln is so much larger than in the other recalcining units. A higher temperature is required to provide the necessary force so that carbon dioxide can be driven out of the center of the larger clumps. Unevenness of particle sizes requires higher temperatures than necessary for the bulk of the particles.[28,29] A schematic diagram of a typical RKC is shown in Fig. 8-7.

It seems unlikely that rotary kilns will find application in recovering lime from wastewater sludges. The RKC requires appreciably more area than either multiple hearth furnaces or fluidized bed reactors. Also, the RKC would be limited only to large installations processing more than 50 tons of product per day. Perhaps more important is the fact that rotary kiln technology is completely foreign to the wastewater treatment field whereas the MHF and the FBR have been successfully applied to the disposal of wastewater sludges for many years.[12,16] As a result, a wealth of experience has been gained in these installations and important modifications have been made, and new designs incorporated, to the original equipment. It could take the manufacturers of rotary kilns a comparable investment, both in time and money, to develop the expertise required to satisfactorily recover lime from wastewater sludges.

HANDLING OF RECLAIMED LIME

The type of process used to recalcine wastewater sludges has a direct influence on the way the reclaimed lime is handled. In the case of the FBR, each type of recalcine reactor produces a unique product; consequently, product handling differs among reactor types.

Handling of Lime from the MHF

As mentioned earlier, recalcined lime from a multiple hearth furnace is discharged at the bottom hearth. Unless operating difficulties cause the formation of lumps (clinkers), the lime discharged from the furnace is a fine, powder-like product. Table 8-4 show the size analysis of a typical sample of recalcined lime taken at Concord, California.[6] As shown in Table 8-2, the discharge temperature of the recalcined product is approximately 399 C (750 F). To protect operating personnel from injury and to avoid the need to use heat resistant material in process equipment, it is advisable to cool the lime to a temperature of 38-93 C (100-200 F). Several types of industrial coolers can be used for this application. At the CCCSD water reclamation plant, water cooled, disc-type coolers will be supplied. After cooling, the reclaimed lime is either transported to storage by mechanical or pneumatic conveyors (see Section V) or it can be classified, using dry techniques, to separate inert solids and other undesirable constituents from the recalcined product.

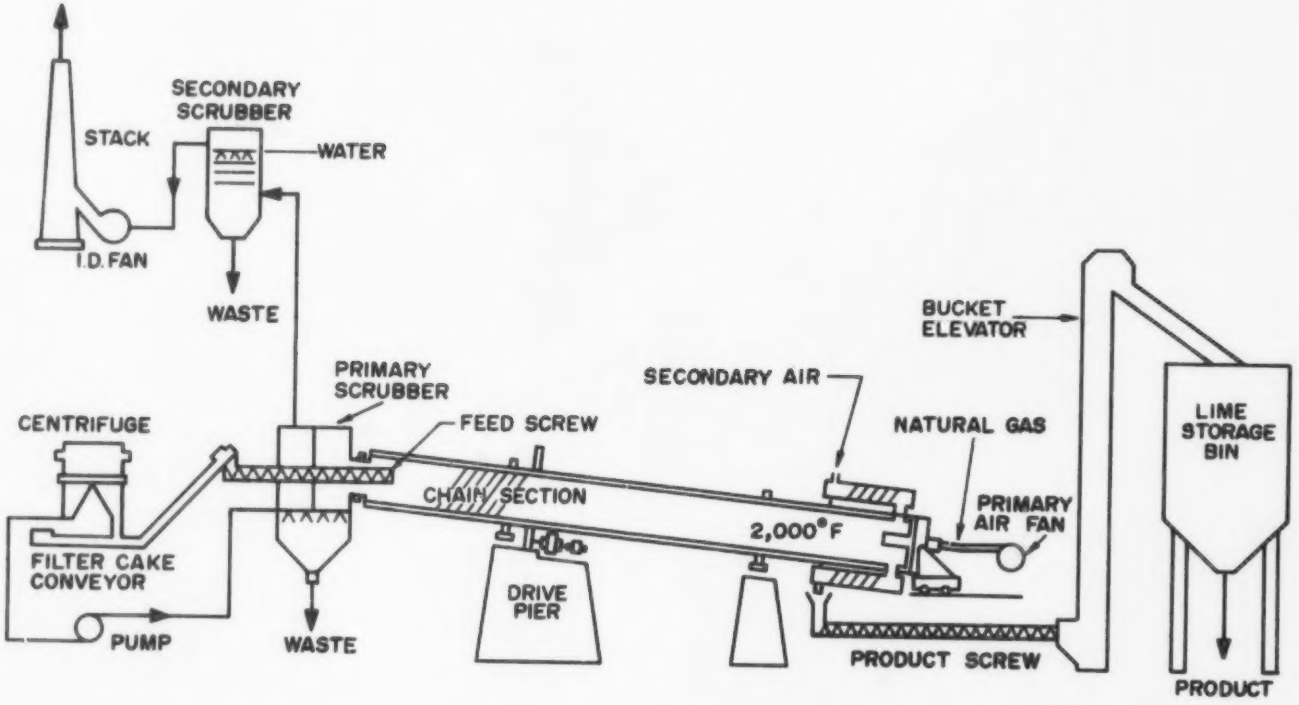

SECONDARY SCRUBBER
STACK
WATER
I.D. FAN
WASTE
BUCKET ELEVATOR
PRIMARY SCRUBBER
SECONDARY AIR
CENTRIFUGE
FEED SCREW
NATURAL GAS
LIME STORAGE BIN
CHAIN SECTION
PRIMARY AIR FAN
2,000°F
FILTER CAKE CONVEYOR
DRIVE PIER
PUMP
WASTE
PRODUCT SCREW
PRODUCT

Figure 8-7 Typical rotary kiln calciner

Table 8-4. SIZE DISTRIBUTION ANALYSIS OF RECALCINED LIME FROM A MHF

Particle size		Weight retained, grams		Percent retained	Cumulative percent passing
U.S. mesh[a]	Microns[b]	Sample 1[c]	Sample 2[d]		
100		0.8100		0.36	99.64
140		1.3091		0.58	99.06
200		1.5756		0.69	98.37
270		3.1673		1.39	96.98
325	44.00	6.2182		2.74	94.24
	34.48		3.3822	1.97	92.27
	31.22		0.8490	0.55	91.72
	24.77		2.5264	1.51	90.21
	15.57		12.5030	7.42	82.79
	11.12		22.8780	13.66	69.13
	7.55		40.3914	24.01	45.12
	3.34		51.0089	30.91	14.21
	1.36		18.7903	11.72	2.49
	<1.36		e	2.49	-

[a] Sieve analysis

[b] Bahco analysis

[c] Weight of sample: 227.0706 grams

[d] Weight of sample: 155.3664 grams

[e] Weight smaller than 1.36μ: 3.0362 grams

Dry Classification of Reclaimed Lime -

Dry (i.e., air) separation of reclaimed lime can be used in lieu of the wet classification process described in Section VII or in addition to it. In the former case, this method of solids separation can be used in conjunction with sludge dewatering by vacuum filters or filter presses (Fig. 7-8). In the latter, dry classification aims at increasing the purity of the recalcined product beyond that obtained by wet classification alone (Fig. 7-9). Dry classification has been found most effective for blowing down silica from the system shown in Fig. 7-9.[6]

Most air classifiers operate on the principle of centrifugal separation combined with the effect of opposing drag forces created by a current of air. The settling rates of particles are increased many times when centrifugal forces are used in place of gravitational acceleration. Once the difference in settling rate between particles of two given sizes has been magnified, the classifier separates them into two groups when centrifugal and drag forces reach equilibrium. The point of equilibrium, at which a particle of certain size is either accepted or rejected by the classifier is called the "cut point". The Envirotech Corporation has found that a cut point at the 45 micron (μ) particle size achieves a partial classification of the acid insoluble inerts (mostly silica) from the other materials. Fig. 8-8 shows the size distribution of a furnace product sample taken during an extended test of lime sludge recycling at CCCSD.[6] It can be seen for this single sample that a fairly good rejection of silica can be obtained while recovering the bulk of the reclaimed lime at cut point points between 20 and 45 μ . The selection of the cut point is best established in field trials. The accepts include fine dust particles ($< 5 \mu$) which normally must be retained for reuse in the process. This is accomplished by a second separation step that takes place in two stages. First in a cyclonic separator where the solid particles are driven by centrifugal force to the cyclone wall while the dust laden air escapes through the gas outlet. Dust is subsequently removed, in the second stage, in a bag type filter. The rejects (coarse) portion after discharge from the classifier is usually carried directly to waste by mechanical or pneumatic conveyors.

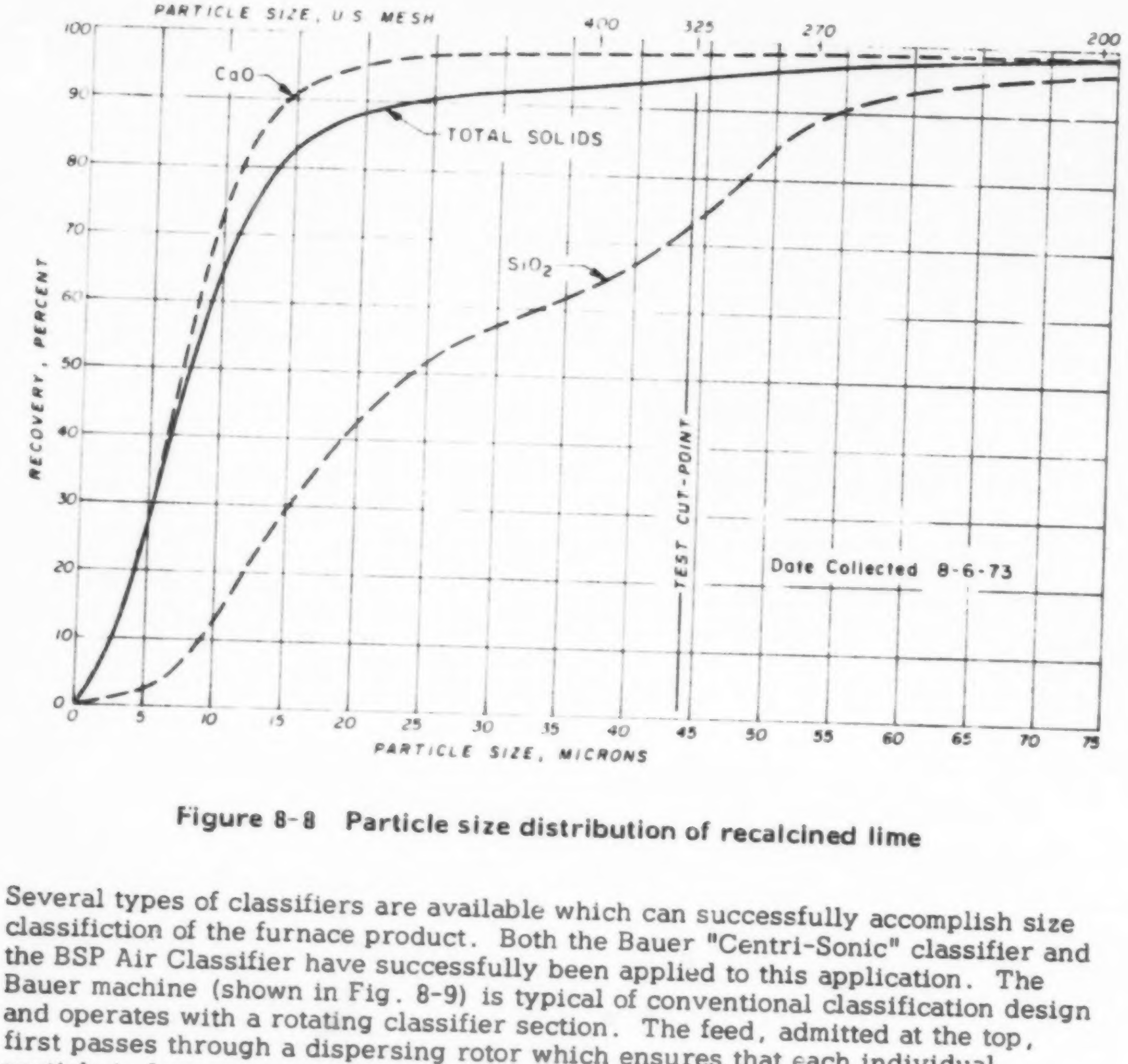
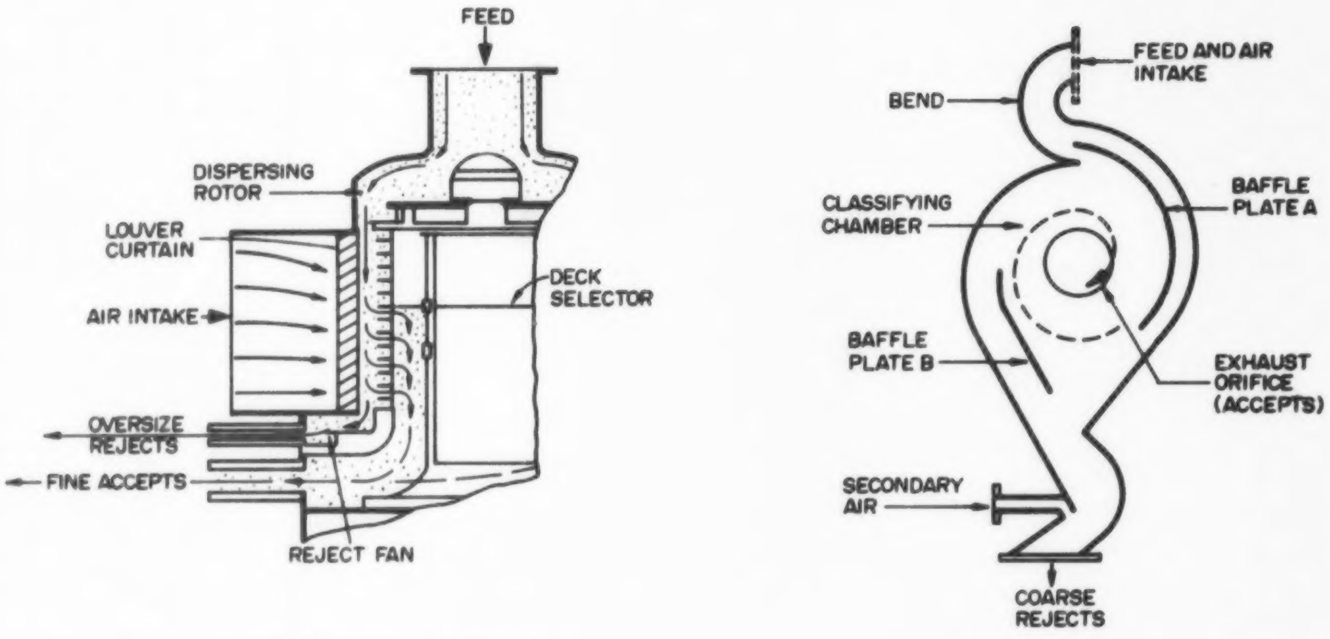


Figure 8-8 Particle size distribution of recalcined lime

Several types of classifiers are available which can successfully accomplish size classifiction of the furnace product. Both the Bauer "Centri-Sonic" classifier and the BSP Air Classifier have successfully been applied to this application. The Bauer machine (shown in Fig. 8-9) is typical of conventional classification design and operates with a rotating classifier section. The feed, admitted at the top, first passes through a dispersing rotor which ensures that each individual particle is free to move in the classifier zone. The particles then move downward between the louver curtain and the rotating classifier where they are intercepted


FEED
DISPERSING ROTOR
LOUVER CURTAIN
AIR INTAKE
DECK SELECTOR
OVERSIZE REJECTS
FINE ACCEPTS
REJECT FAN
FEED AND AIR INTAKE
BEND
BAFFLE PLATE A
CLASSIFYING CHAMBER
BAFFLE PLATE B
EXHAUST ORIFICE (ACCEPTS)
SECONDARY AIR
COARSE REJECTS

BAUER "CENTRI-SONIC"

BSP AIR CLASSIFIER

Figure 8-9 Two types of air classifiers

by a controlled flow of air. The air is forced through the classifier carrying with it the fine particles and excluding the coarse particles which are held out by drag forces. The "cut point" in the Bauer design is determined by the air rate; the classifier speed; the number of deck openings, as fixed by the position of the deck selector; and the rotating classifier design.

The BSP air classifier is unique in that it does not incorporate moving parts (Fig. 8-9). The sharp bend after the introduction of the feed moves the bulk of the solid particles sliding against the inside of baffle plate A leaving a nearly clean gas stream passing on the outside of this baffle plate, next to the chamber wall. At the bottom of baffle plate A, the gas stream crosses a curtain of particles sliding off the inside of the baffle plate producing a separation between the particles, allowing each to react separately to the drag and centrifugal forces induced on it in the chamber. Large particles settle by gravity to the bottom of the chamber. Intermediate size particles and fines flow with the gas in a controlled spiralling stream. Each of these particles is subjected to a centrifugal force, tending to move it to the chamber walls, and to a drag force, created by the gas stream, tending to move the particle to the exhaust orifice. At the "cut point", the two forces are equal. Particles larger than the cut point are affected predominately by centrifugal forces and flow outwardly until they impinge on the chamber wall and settle by gravity to the classifier bottom. Particles smaller than the "cut point" are affected mostly by drag forces and are swept out with the gas stream. The BSP classifier "cut point" is controlled by the chamber dimensions, rate of air flow and secondary air flow.

Fig. 8-10 shows the adaptation of the basic air classification system to the separation of calcium carbonate from inerts in applications involving lime recovery from wastewater sludges.

Using sludge generated at the ATTF, full-scale tests on air classification were conducted at Concord, California[6] in a BSP air classifier. During the course of the Concord tests it was initially felt that the dust collected in the bag filter (see Fig. 8-10) should be wasted from the process; this was done because initial batch testing showed the dust to be high in phosphates. However, when tested at the ATTF with wet classification blowing down phosphorus, the dust did not contain excessive amounts of phosphorus. Table 8-5 compares the phosphorus and other constituent levels in the accepts to those in the dust during a period in the ATTF operation when the process was believed to be close to steady state. Due to the small effect of phosphorus, dust was returned to the process along with the other accepts.

Dry classification performance is expressed similarly to wet classification performance; for good classification, high recovery of calcium oxide to the accepts and dust is desired with low recovery of all other constituents. As shown in Table 8-6, essentially no classification of calcium oxide from the other constituents occurred, except for silica and iron. The period of July 27 to August 30 represented production operation of the classifier during the lime recycle project. The runs on September 20 represented an attempt to operate the classifier closer to design conditions. During the production runs, the classifier was not loaded

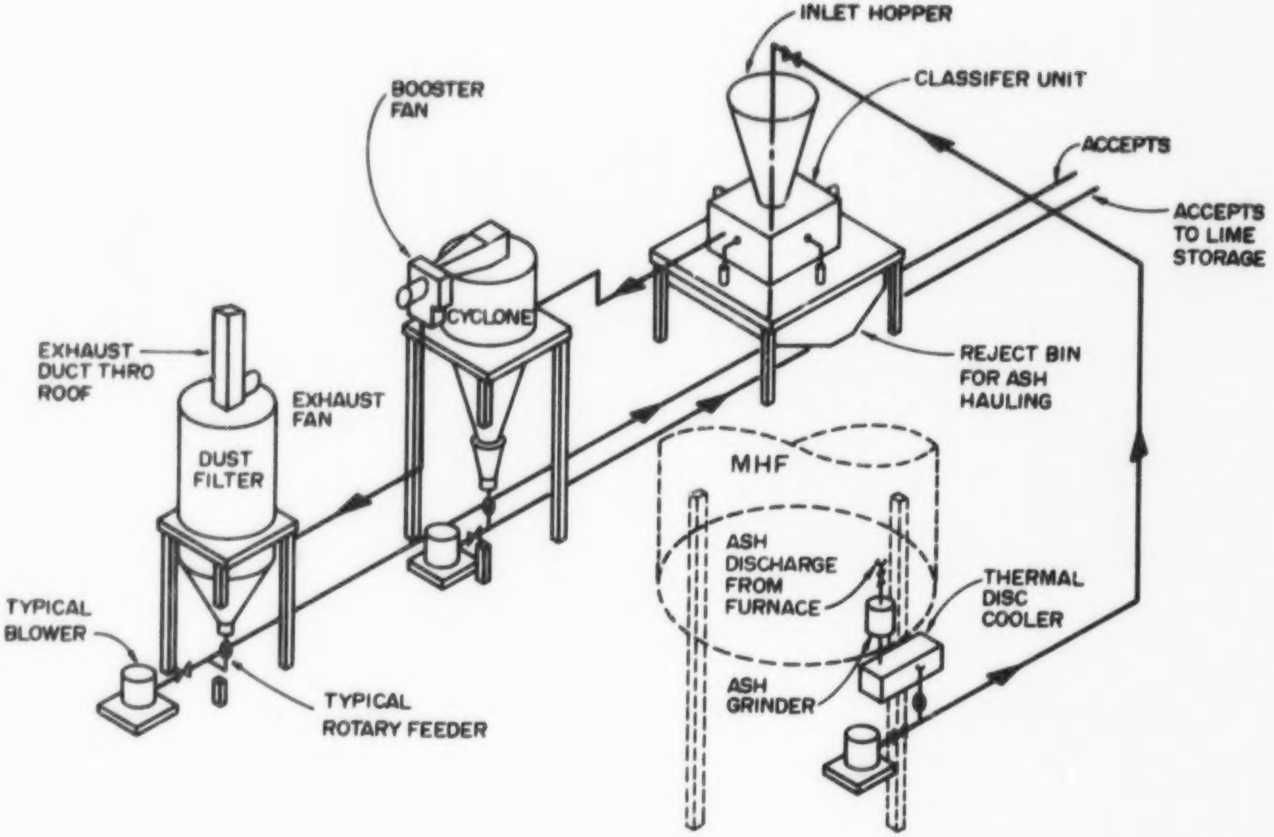

INLET HOPPER
BOOSTER FAN
CLASSIFER UNIT
ACCEPTS
ACCEPTS TO LIME STORAGE
CYCLONE
EXHAUST DUCT THRO ROOF
EXHAUST FAN
REJECT BIN FOR ASH HAULING
DUST FILTER
MHF
ASH DISCHARGE FROM FURNACE
THERMAL DISC COOLER
TYPICAL BLOWER
ASH GRINDER
TYPICAL ROTARY FEEDER

Figure 8-10 Dry classification of recalcined lime (courtesy of Envirotech Systems, Inc.)

Table 8-5. COMPARISON OF ACCEPTS AND DUST COMPOSITION DURING ATTF TEST WORK

Date	Sample	Calculated composition, percent dry weight						
		CaO	MgO	$CaCO_3$	$Ca_3(PO_4)_2$	Fe_2O_3	SiO_2	Other
August 6, 1973	Accepts	61.9	4.3	7.4	7.0	1.6	11.1	0.9
	Dust	58.3	6.9	13.5	10.1	1.4	1.2	0.3
August 10, 1973	Accepts	60.4	4.5	7.4	7.2	1.5	10.7	2.3
	Dust	61.4	8.2	10.1	10.2	1.4	0.6	1.6
August 12, 1973	Accepts	61.1	4.0	3.5	7.1	1.7	15.5	1.1
	Dust	64.6	5.7	5.8	9.7	1.6	3.0	1.3

Table 8-6. COMPONENT RECOVERIES IN CLASSIFICATION TESTS DURING ATTF TEST WORK

Date (1973)	Classifier load		Recovery to accepts and dust of stated constituent, percent							Total recovery, percent
	kg/hr	lb/hr	CaO	SiO_2	MgO	$CaCO_3$	$Ca_3(PO_4)_2$	Fe_2O_3	Other	
July 27	--	--	99.2	84.6	98.2	98.2	98.0	91.4	96.8	98.1
July 31	--	--	99.2	80.6	98.1	99.0	97.8	92.2	96.3	97.8
Aug. 6	729	1,607	93.8	88.6	93.1	93.1	93.1	92.0	85.7	93.0
Aug. 12	670	1,477	95.5	92.2	95.3	95.8	95.0	94.3	94.8	94.9
Aug. 14	592	1,305	98.5	95.1	98.6	97.8	98.2	97.1	97.4	97.9
Aug. 16	562	1,240	96.3	93.9	95.4	95.5	96.0	94.7	94.9	95.5
Aug. 18	718	1,583	97.6	92.7	95.8	96.1	97.1	94.9	94.3	96.8
Aug. 20	622	1,382	94.8	89.4	93.4	96.5	94.0	92.3	98.3	94.1
Aug. 22	702	1,548	97.5	94.8	98.2	96.3	97.2	96.1	81.0	97.1
Aug. 24	730	1,609	97.6	92.0	97.1	97.5	97.0	95.4	75.9	96.4
Aug. 26	848	1,870	98.2	92.6	97.9	97.1	97.3	95.8	100.0	97.0
Aug. 28	776	1,710	98.8	94.7	98.8	93.8	98.1	96.7	100.0	98.0
Aug. 30	789	1,740	96.7	90.3	95.7	98.4	95.7	93.6	99.1	95.1
Mass average[a]	703[b]	1,551[b]	97.3	91.8	96.8	97.7	96.6	94.5	95.4	96.5
Sept. 20-1	227	500	98.2	79.0	95.5	97.9	94.6	88.0	84.2	94.5
Sept. 20-2	227	500	97.6	67.6	96.1	98.5	95.2	84.1	93.3	93.8
Sept. 20-3	454	1,000	98.5	78.8	97.3	98.6	96.6	84.7	97.3	96.0
Mass average[c]	303	667	98.1	76.1	96.6	98.4	95.7	86.4	92.9	94.4

[a] July 27 to Aug. 30
[b] Excluding July 27 and 31
[c] Sept. 20 only

on a steady set basis. Furnace product, that had been stored in the thermal disc cooler (see Case History) and a water jacket conveyor, was loaded into the classifier on an intermittent basis. This resulted in surges in operation which adversely affected process efficiency. Constant rate operation on September 20, 1974 produced performance consistent with Envirotech's previous experience.

Even under the best conditions, the rejection of silica and iron is not high as compared to the rejections obtained for most constituents in wet classification. Nonetheless, silica is not classified well in the wet classification process; therefore, dry classification provides a means to blow down additional amounts of a difficult to reject constituent. As will be shown in Section X, dry classification is a more efficient means of blowing down silica than direct wasting of the furnace product.

Handling of Lime from the FBR

As described earlier, lime recovered in a pellet bed reactor is discharged from it in pelletized form. Recalcination of water softening sludges and pulp and paper mill sludge shows that the product obtained in these applications is a dense, dust free lime pellet which can be handled without difficulty in mechanical or pneumatic conveyors (see Section V). A typical size distribution for this material is given in Table 8-7.[30]

Table 8-7. TYPICAL SIZE DISTRIBUTION FOR PELLETS FROM A FLUIDIZED BED CALCINER

Accumulative weight retained, percent	U.S. Sieve series
1.5	6
13.5	8
24.6	10
50.1	14
81.5	20
19.5[a]	< 20

[a] Weight with particle size smaller than 20 mesh

A distinctive feature of the sand bed FBR used in wastewater sludge applications (see Fig. 8-6) is the handling of reclaimed lime in slurry form. The problems associated with lime slurry handling were described in Section VI under Lime Addition. The National Lime Association lists several corrective measures to minimize scaling problems.[31] Engineers considering a sand bed FBR to recover lime from wastewater sludges should give careful attention to these types of problems and provisions to either correct or alleviate them should be incorporated into the design.

Handling of Lime from the RKC

As shown in Fig. 8-7, reclaimed lime discharged from a RKC (rotary kiln calciner) is transported to storage via mechanical conveyors. Since the nodulized product from a kiln occasionally includes large lumps, up to 15-20 cm (6-8 inch) in size,[32] the recalcined lime is normally screened so only 1.9-2.5 cm (3/4 - 1 inch) particles are discharged to the screw conveyor. In the lime reclamation plant at Miami, Florida, lumps retained in the screen are put through a crusher and then fed to the same screw conveyor.[32] Reclaimed lime, discharged at approximately 316 C (600 F) from the RKC, is not usually cooled prior to storage; mechanical conveyors must therefore be designed to handle the hot product.

RELATED PROCESSES

Incineration is not the ultimate means to dispose of wastewater sludges. All combustion processes yield two end products: a solid residue or ash and a gaseous product, usually called exhaust or off-gases. Both have important effects on the environment and must therefore be subjected to further treatment before final disposal. Furthermore, off-gases are a source of heat that can be recovered. Methods used to handle ash are covered in detail in Section XI. Handling of exhaust gases is described in the following paragraphs. A third environmental concern, noise, is often associated with incineration systems. Since noise and its control in areas where operators are present is receiving increasing attention by federal and state authorities, methods to reduce noise levels around incineration installations will also be briefly reviewed.

Off Gases Scrubbing

It has been stated[33] that uncontrolled gases emitted from the MHF and the sand bed FBR contain approximately 0.9 and 8.0 grains per dry standard cubic foot (gr/dscf) of particulate matter respectively. Since the air quality standards (see Section IX) limit particulate emissions to the atmosphere to 0.03 gr/dscf maximum, high efficiency scrubbers are required to reduce incinerator emissions to acceptable levels.

Particle collection equipment has been classified[34] as follows:

"1. High-efficiency, high-cost collectors:
    a. Electrostatic precipitators.
    b. Sonic agglomerators.

2. High-efficiency, moderate-cost collectors:
    a. Fabric or fibrous filters.
    b. Wet collectors, packed towers, scrubbers, and centrifugals.

3. Low-cost, lower efficiency designs:
    a. Cyclones and dry centrifugals.
    b. Dry dynamic.
    c. Inertial."

To control the emission of particulate matter, multiple hearth furnaces are usually equipped with inertial wet scrubbers of the impingement baffle or Venturi designs. In fluidized bed reactors, due to their operational features which result in higher emission of particulates, the wet scrubber is often preceeded by dry cyclones which reduce the dust load of the secondary (wet) collector.

The MHF used to recalcine lime from wastewater sludge can be expected to have higher particulate emissions than units burning organic sludges. This is due not only to the characteristics of the feed material but also to the fact that classified lime sludge cakes, at 50-60 percent solids concentration, would tend to dry in the top hearth (feed hearth) where the off-gases are removed from the furnace. Dried particles could then be carried by the outgoing gases. In one testing and two full-scale installations, the dust load from multiple hearth furnaces recalcining lime has been found to average approximately 30 lb per 1000 lb of exhaust gases. The dust loading would sometimes justify the use of a cyclonic precleaner ahead of the wet collector. Cyclones are highly efficient in removing medium and coarse dust particles. Particulate matter collected in the dry cyclone, containing an appreciable percentage of calcium carbonate, can be returned to one of the furnace's burning hearths for recalcination. To minimize carry over of small lime particles (passing a 200 mesh), the gas velocity inside a MHF should be maintained below 10 fps.[14]

Fig. 8-11 shows the arrangement of the scrubbing equipment for the lime recalcination furnaces at the CCCSD water reclamation plant. The wet scrubber is a three stage venturi-spray unit designed for low head loss operation. Besides removing particulate matter, wet scrubbers also cool the off-gases to avoid the formation of a steam plume. A temperature of approximately 43 C (110 F) is required to suppress a stack plume.[12]

A more detailed review of gas cleaning techniques is beyond the scope of this report. The reader is referred to a series of reports published by the American Petroleum Institute on the Removal of Particulate Matter from Gaseous Wastes for a comprehensive coverage of this subject. (Reference 34 is part of this series). Selection of scrubbing equipment should be made in consultation with the manufacturers of incineration systems or even left entirely to them if a performance specification, warranting compliance with the applicable air pollution standards, is used to select the incineration equipment.

Waste Heat Recovery

Incineration of wastewater sludges requires that sufficient heat be generated: 1) to evaporate the remaining moisture from dewatered cakes, and 2) to ignite and burn the dried sludge. Furthermore, when lime is to be recovered, additional heat is required to convert calcium carbonate in the sludge to calcium oxide. Heat is derived from combustion of volatile matter in the sludge and from auxiliary fuel supplied through the incinerator burners. Heat generated by combustion leaves the incinerator in the exhaust gases, in the hot ash product, and, in the case of the MHF, in the air used to cool the central shaft.

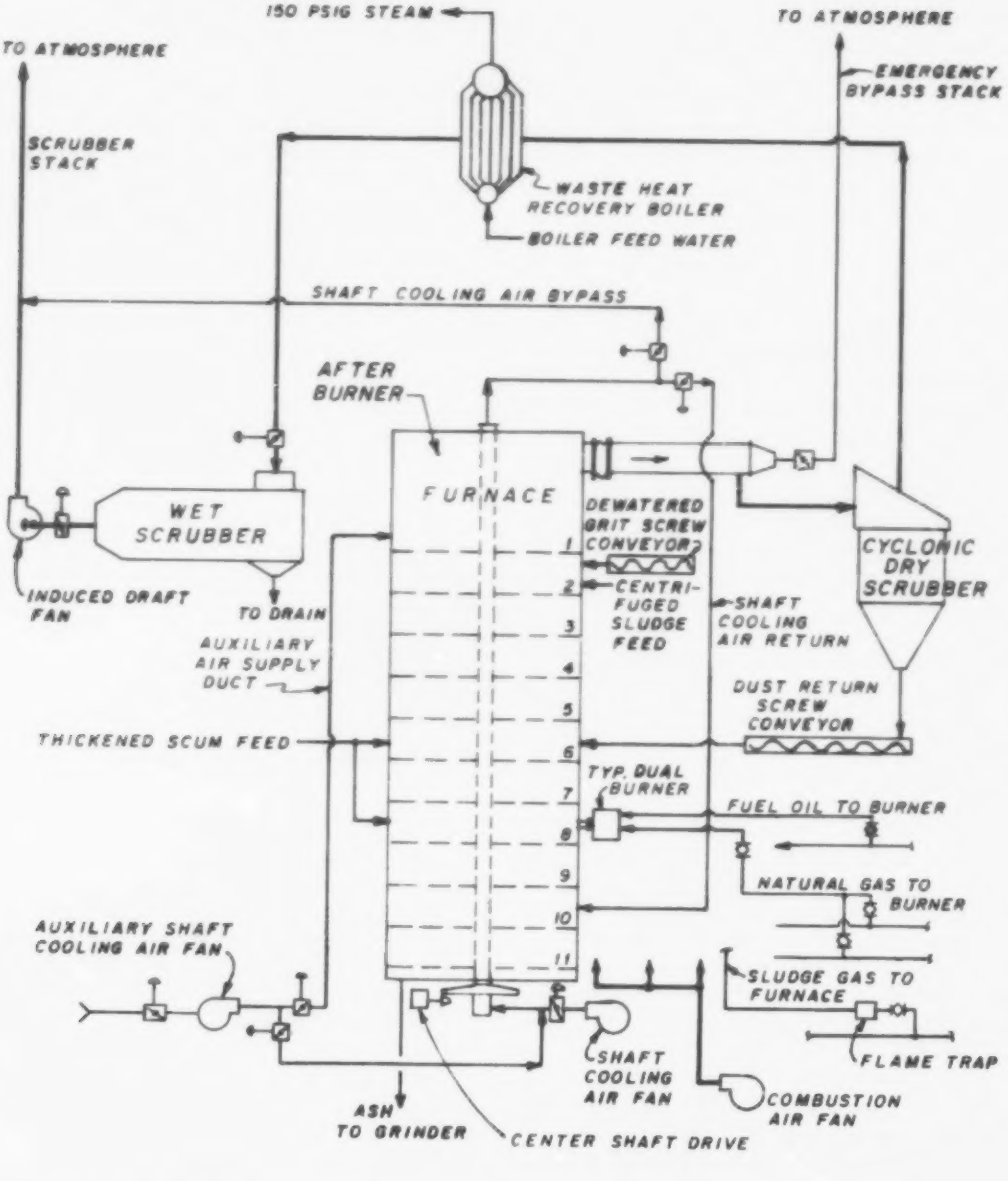

150 PSIG STEAM
TO ATMOSPHERE
TO ATMOSPHERE
EMERGENCY BYPASS STACK
SCRUBBER STACK
WASTE HEAT RECOVERY BOILER
BOILER FEED WATER
SHAFT COOLING AIR BYPASS
AFTER BURNER
FURNACE
WET SCRUBBER
DEWATERED GRIT SCREW CONVEYOR
CYCLONIC DRY SCRUBBER
1
2
3
4
5
6
7
8
9
10
11
CENTRIFUGED SLUDGE FEED
SHAFT COOLING AIR RETURN
INDUCED DRAFT FAN
TO DRAIN
AUXILIARY AIR SUPPLY DUCT
DUST RETURN SCREW CONVEYOR
THICKENED SCUM FEED
TYP. DUAL BURNER
FUEL OIL TO BURNER
NATURAL GAS TO BURNER
AUXILIARY SHAFT COOLING AIR FAN
SLUDGE GAS TO FURNACE
FLAME TRAP
SHAFT COOLING AIR FAN
COMBUSTION AIR FAN
ASH TO GRINDER
CENTER SHAFT DRIVE

Figure 8-11 Auxiliary equipment for a MHF at the CCCSD water reclamation plant

The heat loss in the hot ash product cannot be recovered economically but is normally a small fraction of the total heat generated. Heat losses by radiation to the surroundings are minimized by the use of thermal insulation. The other two ways in which heat may leave the incinerator, and heat recovery methods applicable to them, are discussed below.

In multiple hearth furnaces, the heat contained in the warmed shaft cooling air, at a temperature of 149-260 C (300-500 F), would normally be recovered by using it as part of the combustion air, thus reducing fuel requirements. As mentioned earlier, in the pellet bed calciner (see Fig. 8-4), the reactor off-gases are used to dry the lime sludge before it is fed to the FBR, thereby practically eliminating the need for auxiliary fuel to evaporate water in the reactor. In the sand bed units (see Fig. 8-6), the drying step has been eliminated so no heat recovery step is inherent.

Apart from the heat recovery features included in multiple hearth and fluidized bed incineration systems, heat can be recovered from incinerator off-gases by using them to generate steam in a waste heat boiler. A waste heat boiler is essentially a heat exchanger in which heat is extracted from hot gases and transferred to water to generate steam. A water-tube type (water inside the boiler tubes, hot gases outside the tubes) is generally to be preferred over a fire-tube type boiler (gas inside the tubes, water outside).[36] A basic water-tube boiler would consist of two steel boiler drums placed one above the other, with a multiplicity of small diameter boiler tubes connecting the two drums. Drums and tubes are enclosed in a refractory lined housing having an inlet and an outlet for the gases from which heat is being reclaimed. The heat recovered with a typical waste heat boiler is approximately 75 percent of that contained in the hot gases at a reference temperature of 15.6 C (60 F). This value is an assumed average ambient temperature which is customarily used in combustion calculations. Heat losses to the surroundings from the casing would be about two percent of the heat transferred from hot gases to steam.

For the CCCSD water reclamation plant, each multiple hearth furnace has been provided with a waste heat boiler. Each boiler is capable of generating 15,870 kg/hr (35,000 lb/hr) of steam at a pressure of 10.5 kg/sq cm (150 psig) and a temperature of 185 C (365 F).[37] Heat is obtained from 52,200 kg/hr (115,000 lb/hr) of exhaust gases leaving the furnace at 760 C (1400 F). In passing through the boiler and generating steam, the gases are cooled to approximately 232 C (450 F). The high pressure steam produced is used to power turbine-driven aeration blowers and boiler feed water pumps and to supply heat to the plant's air conditioning and heating systems.

In Fig. 8-11, a waste heat recovery boiler in a typical MHF at the CCCSD plant has been shown. Worth noticing is the location of the dry cyclone precleaner provided ahead of the wet scrubber, which also reduces the load of fly ash going to the boiler. In the design of the boiler, particular attention should be given to the dust load and the size of the particles entering the boiler.

Heat recovery can be expressed as a percentage of the heat input to the incinerator by making a complete heat balance for the incinerator and the waste heat boiler. To make this balance the following parameters must be known: feed rate and composition of the sludge; heat of combustion of the sludge volatile solids; amount of excess air and furnace temperature required for complete combustion; and physical dimensions and thermal characteristics of the incinerator. In addition to the parameters just listed, the properties and heating value of the fuel must also be known. The heating value of fuels is expressed in two ways, (1) as the high heat value (HHV) also known as "gross" heat value and (2) as the low heat value (LHV), also called the "net" heat value. The essential difference between the HHV and the LHV is the heat of condensation of water equivalent to the hydrogen contained in the fuel. Because the water formed in combustion always leaves the furnace as water vapor (uncondensed), the heat of condensation of the water is unavailable for use. Therefore, in combustion calculations, the LHV is the one normally used.

The heating value of gaseous fuels is usually expressed as the HHV of 0.028 cu m (one cubic foot) of the gas measured at 15.6 C (60 F) and a pressure of 76 cm (30 inches) of mercury. Thus, a stated heating value of 9,450 kcal/cu m (1,050 Btu/cu ft) for natural gas normally means the HHV for the conditions stated. The LHV for such a gas would be about 8,550 kcal/cu m (950 Btu/cu ft), the exact difference between the HHV and the LHV depending upon the gas composition. For liquid and solid fuels, the heating values are normally expressed in kcal/kg (Btu/lb). Approximate heat values for common petroleum fuel oils are given in Table 8-8.

Table 8-8. TYPICAL HEAT VALUES OF FUEL OILS

Type	Weight		Heat values, kcal/kg (Btu/lb)	
	kg/cu m	lb/gal	HHV	LHV
No. 6 - Heavy	17.85	8.34	10,290(19,540)	9,730(17,540)
No. 6 - Light	16.67	7.79	10,560(19,020)	9,950(17,930)
No. 2 (Diesel)	14.72	6.88	10,960(19,750)	10,270(18,510)

Noise Control

Noise can be defined as undesired sound. The intensity of sound is usually measured in decibels (dBA), a term that expresses the relative magnitude of a particular sound when compared to a reference sound pressure level. One decibel is equal to a force of 0.002 dyne per square centimeter. It is important to keep in mind that decibels are measured not on an arithmetic but on a logarithmic scale. Thus a reduction of 3 dBA is almost a 50 percent reduction of noise energy. Typical sound levels are given in Table 8-9.[36]

Table 8-9. TYPICAL SOUND LEVELS

Class	Found in	Sound level, dBA
Very faint (threshold of audibility)	Sound proof room	10
Faint	Whisper	20
	Quiet conversation	30
Moderate	Private office	40
	Average conversation	50
	Average office	50
Loud	Average factory	60
	Average street noise	70
Very loud	Noisy office	80
	Noisy factory	90
	Unmuffled truck	90
Deafening	Loud street	100
	Boiler factory	100
	Nearby riveter	110
Threshold of feeling		120

The Occupational Safety and Health Act of 1970 (OSHA) considers noise above certain established levels as occupational hazards, i.e., possible loss of hearing, and has established limits of exposure for workers subjected to noisy environments. Table 8-10 shows permissible noise exposure set forth by OSHA. Federal and state industrial safety orders have also limited the degree of noise exposure that employees may endure without ear protection devices.

Due to the auxiliary equipment normally associated with sludge incineration systems, a large number of noise sources are located near incinerators. Generally speaking, the sound produced by a machine is directly related to the horsepower input to it. Also, high speed machines are noisier than low speed units. As an example, Table 8-11 gives estimated sound pressure levels for one of the multiple hearth furnaces at the CCCSD water reclamation plant.[38] The values given are for the equipment operated alone without background noise. As seen in Table 8-11, the noise level is controlled by fan and blower noise. Since several pieces of equipment operate simultaneously, the overall sound pressure level will be higher than shown in the table. For example, if the maximum noise level allowed in the incineration area is set at 95 dBA, the noise produced by the shaft cooling fan has to be lowered to meet the combined noise level.

Table 8-10. PERMISSIBLE NOISE EXPOSURES

Sound Level, dBA	Duration per day, hours
90	8
92	6
95	4
97	3
100	2
102	1-1/2
105	1
110	1/2
115	1/4 or less

Table 8-11. SOUND PRESSURE LEVEL OF MHF EQUIPMENT

	Motor HP	dBA @ 3 ft distance
Furnace		
Center shaft drive	15	70
Center shaft cooling air fan	20	95
Combustion air fan	40	85
Induced draft fan	50	85
Lump breaker (intermittent)	1 1/2	90
Lump breaker (continuous)		80
Ash cooler	10	65
Screw conveyor	2	60
Pneumatic conveyor air lock valve	1/2	50
Pneumatic conveyor air blower	10	90
Air classification system		
Feed bin vibrator (full bin)		30
Feed bin vibrator (empty bin)		70
Rotary feeder	1/2	50
Air classifier	25	86
Air filter (intermittent)		90
Pneumatic conveyor air blower	15	90
Ash bin discharge screw conveyor	3	60

Several techniques can be applied to control noise. The level of sound generation of the source can be reduced. Examples of this approach are the installation of acoustic enclosures around the entire fan or blower assembly, the addition of inlet and discharge silencers, and the use of low noise electric motors. Equipment enclosures have resulted in average reductions of 4 dBA.[39] Intake silencers can reduce inlet noise levels by 10-15 dBA,[38,40] while discharge mufflers have resulted in an additional reduction of 6 dBA.[39] Reductions of 4 dBA in the sound pressure level have been reported for blowers enclosed in acoustic shields.[39] When the incineration equipment is housed in a building, further reduction can be obtained by adding absorbing material to the walls to reduce the reverberant sound level. Dobbs[40] has reported that a noise reduction of approximately 8-10 dBA could be accomplished with the use of 3-inch thick glass fiber boards for acoustical absorption.

Vibration isolation is another method of noise control. Large fans and blowers should be mounted on a heavy inertia base and attached to it with vibration isolators of the combined spring and rubber type.[40] Since piping can transmit the sound generated by machinery, the junction between equipment and ducts should be through a flexible connector. The flexible connectors should have sufficient mass to be at least equal to that of the duct walls.[40] Lead loaded vinyl or rubber are thus better insulators than the canvas fabric found in standard connectors.

SUMMARY OF LIME RECOVERY CASE HISTORIES

Several wastewater treatment plants have practiced lime recovery either on an experimental or full-scale basis. Information is available from two tertiary treatment plants (South Tahoe and Piscataway) and two plants practicing primary lime addition (Blue Plains and Central Contra Costa). A brief description of the lime recovery operations in each of these four plants is given below.

South Tahoe Water Reclamation Plant

The water reclamation experiences at the South Tahoe plant have been extensively documented and reported. Reference 2 of this section is a report covering three years operation of the 7.5 mgd advanced wastewater treatment plant. The summary that follows highlights the thickening, dewatering and recalcination processes only.[41]

At South Tahoe, secondary effluent from the activated sludge process is treated with lime, clarified, passed through an air scrubber to remove ammonia, recarbonated, and finally treated by filtration and carbon adsorption. Sludges from the lime clarifier and recarbonation basin are first gravity thickened and then dewatered in a solid bowl centrifuge. The sludge cake is calcined and recycled for reuse along with makeup lime in the lime clarifier. A second centrifuge dewaters the centrate from the first unit and its cake is conveyed to an organic sludge MHF. The first centrifuge is a concurrent type one and is operated in a wet classification mode (see Section VII). The centrate is sent to the second centrifuge of the same type where the remaining solids are removed. The centrifuges can be operated at 2200, 1800, or 1600 rpm. Initial tests were carried out on the lime mud feed stream to determine optimum operating speed.[2] Data showed approximately the same percent solids in the cake and the same recovery of solids at all three speeds. The lowest speed was selected to reduce wear and maintenance.

At South Tahoe it has been found that the percent capture or recovery of lime into the first stage cake decreases linearly with increasing feed rate of lime sludge. At approximately 8 percent solids in the feed, 93 percent capture was achieved at a feed rate of 10 gpm. When the feed rate was increased to 20 gpm, solids capture dropped to 79 percent.[41]

The South Tahoe report[2] states that at a flow of 7.5 mgd through the water reclamation plant, the total blowdown of waste solids from the lime clarification operation would be about 17 tons per day of lime mud (dry CaO basis) if there were no lime recovery. With lime recovery, this quantity is reduced to about 1.5 tons per day. The cost of recalcined lime at Tahoe ($31.61/ton CaO) is slightly higher than that of make up lime. This figure however, does not take into account the savings in sludge disposal realized through reduction of the solids volume achieved by incineration and the on-site production of CO_2 for recarbonation.

The centrifuged cake is fed by a belt conveyor to a 4.1 m (14.3 ft) diameter, six hearth MHF. The recalcined lime is discharged by gravity through a crusher to a thermal disc cooler where lime temperatures are lowered from 371 C to 38-66 C (700 F to 100-150 F). Cooled lime drops into a rotary air lock and is pneumatically conveyed to a 35 ton capacity recalcined lime storage bin for reuse. Stack gases are scrubbed in a multiple tray scrubber before being exhausted to the atmosphere. A portion of the gases are recycled to the recarbonation system. Solids are continuously wasted to prevent a buildup of inerts in the recycled product.

Since 1968 the South Tahoe plant has successfully recalcined lime sludge from the lime chemical treatment process. Over this period makeup lime has accounted for only 28 percent of the calcium oxide used. Monthly CaO values in the recalcined lime have averaged 66.0 percent over the entire period.[2] A reduction of approximately 40 percent in fuel requirements was achieved when centrifugal classification was used rather than whole sludge recovery.[2]

The influence on lime activity of recalcined temperature, rabble arm speed and feed rate were investigated at South Tahoe. Of the three parameters, temperature had the most effect on recalcined lime activity. The CaO content in the recalcined lime was increased 15 percent by raising the temperatures from 871 to 1038 C (1600 to 1900 F). At nine tons of solids to the MHF per day, the optimum recalcining conditions were 1038 C (1900 F) on hearths numbers 4 and 5 with a 1.5-2.0 rpm rabble arm speed.

Fig. 8-12 is a schematic diagram of the lime sludge handling facilities at South Tahoe.[2]

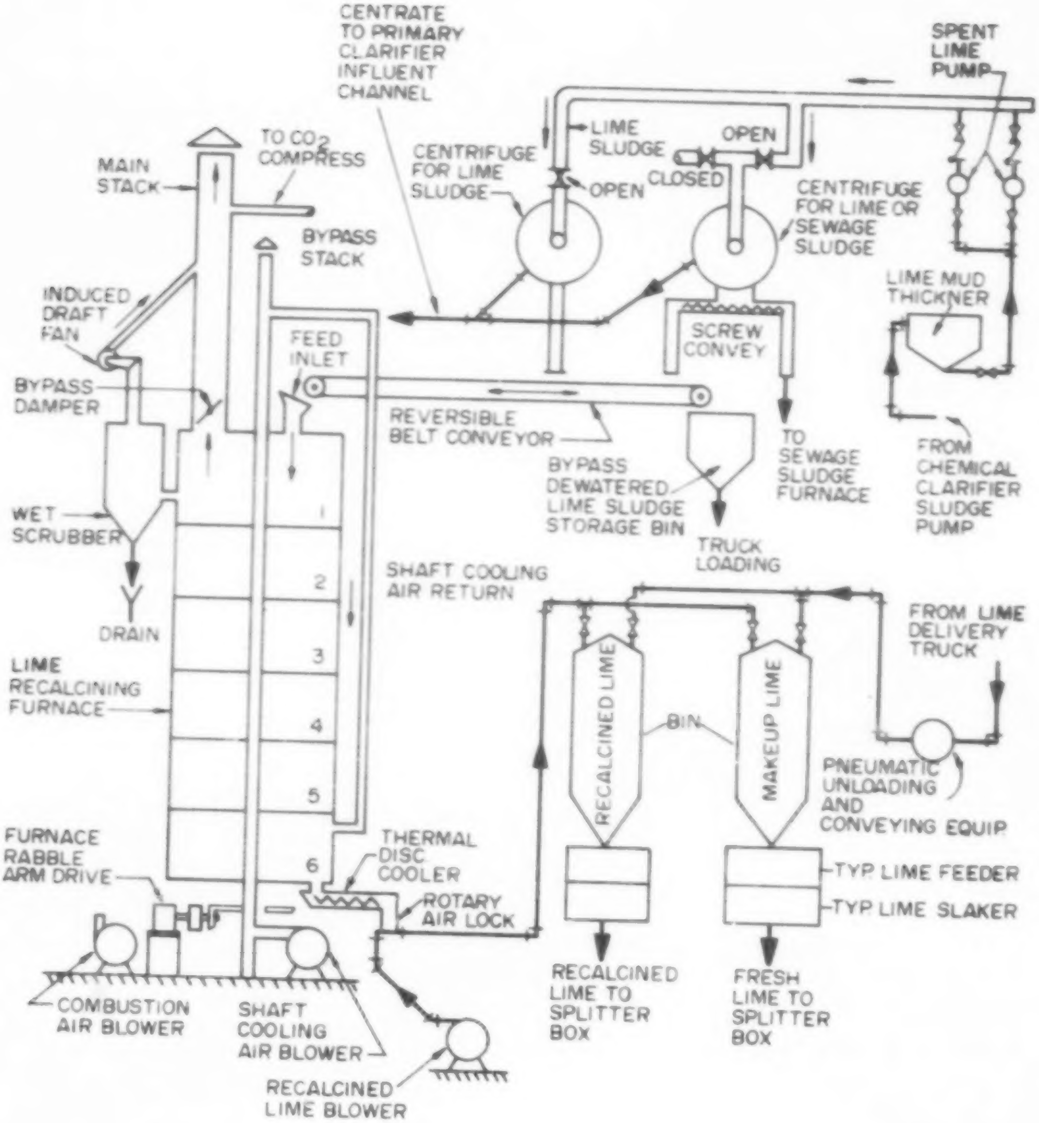

CENTRATE TO PRIMARY CLARIFIER INFLUENT CHANNEL
SPENT LIME PUMP
TO CO2 COMPRESS
MAIN STACK
LIME SLUDGE
OPEN
CENTRIFUGE FOR LIME SLUDGE
OPEN
CLOSED
CENTRIFUGE FOR LIME OR SEWAGE SLUDGE
BYPASS STACK
INDUCED DRAFT FAN
LIME MUD THICKNER
FEED INLET
SCREW CONVEY
BYPASS DAMPER
REVERSIBLE BELT CONVEYOR
TO SEWAGE SLUDGE FURNACE
FROM CHEMICAL CLARIFIER SLUDGE PUMP
BYPASS DEWATERED LIME SLUDGE STORAGE BIN
WET SCRUBBER
TRUCK LOADING
1
2
3
4
5
6
SHAFT COOLING AIR RETURN
DRAIN
FROM LIME DELIVERY TRUCK
LIME RECALCINING FURNACE
RECALCINED LIME
BIN
MAKEUP LIME
PNEUMATIC UNLOADING AND CONVEYING EQUIP
FURNACE RABBLE ARM DRIVE
THERMAL DISC COOLER
TYP. LIME FEEDER
ROTARY AIR LOCK
TYP. LIME SLAKER
COMBUSTION AIR BLOWER
SHAFT COOLING AIR BLOWER
RECALCINED LIME TO SPLITTER BOX
FRESH LIME TO SPLITTER BOX
RECALCINED LIME BLOWER

Figure 8-12 Lime recovery at the South Tahoe water reclamation plant

Piscataway Advanced Wastewater Treatment Plant

The EPA is supervising the operation of a 0.22 cu m/sec (5 mgd) tertiary facility at Piscataway, Maryland. The system employs two-stage lime treatment, effluent filtration and activated carbon adsorption (Fig. 8-13). A single sludge dewatering stage (centrifugation) is employed. Because the centrifuge is operated at high recovery, the inerts are retained in the recalcined lime.[42]

The recalcined product has an available lime index of 60 percent. The calcium oxide content might even be lower if it were not for the fact that the secondary effluent is low in phosphorus concentration (3.1 mg/l as P). During a 36-day operating period when 26 percent of the furnace produce was blown down, 68 percent of the total dose of 271 mg/l CaO was recalcined lime. The resulting pH for this operation was 11.45. Secondary effluent alkalinity is approximately 100 mg/l as $CaCO_3$.[42]

Blue Plains Advanced Wastewater Treatment Plant

A two and one-half month test of lime recovery from combined sludges has been conducted at the EPA-DC Blue Plains Pilot Plant.[43] The system consisted of an Independent Physical Chemical treatment (IPC) pilot plant with two stage lime precipitation, dual media filtration and granular carbon adsorbtion treating District of Columbia raw wastewater at 189,000 lpd (50,000 gpd). The first stage of clarification with lime addition was operated at approximately pH 11.5 while the second stage with CO_2 recarbonation was operated at pH 10.0-20.5 with an Fe^{+++} dosage of 5 mg/l as added flocculant. Solids from the clarification system were gravity thickened to 9-13 percent solids and classified in a Sharples model P600, 6-in. diameter solid bowl centrifuge to separate carbonate and noncarbonate solids. The centrifuge cake at 51 percent solids was calcined in a multiple hearth furnace, mixed with make-up lime and recycled to the clarification system. The centrate was wasted from the lime recycle system and dewatered by alternate centrifugation, vacuum filtration and pressure filtration systems.

The classification centrifuge operated at approximately 74 percent solids recovery. At this solids recovery the constituent recovery of $CaCO_3$ averaged 93.0 percent while that of $Ca_3(PO_4)_2$, $Mg(OH)_2$ and volatile solids averaged 37.3, 46.0 and 41.3 percent, respectively. The classification centrifuge prevented a buildup of inert materials in the recalcined product; during the test period, the fraction of calcium oxide hovered between 70 and 80 percent. During the test period, the fraction of reclaimed lime of the total dose was 72.5 percent.

Comparing the use of virgin lime or recalcined lime, effluent qualities of the IPC system were equivalent during periods when the plant was run under computer control. The comprehensive investigations of the Blue Plains investigators in the area of dewatering second stage centrate has been summarized in Section VII.

Central Contra Costa Sanitary District Water Reclamation Plant

In connection with the design of the CCCSD's Water Reclamation Plant, test work has been conducted at its Advanced Treatment Test Facility on the reclamation

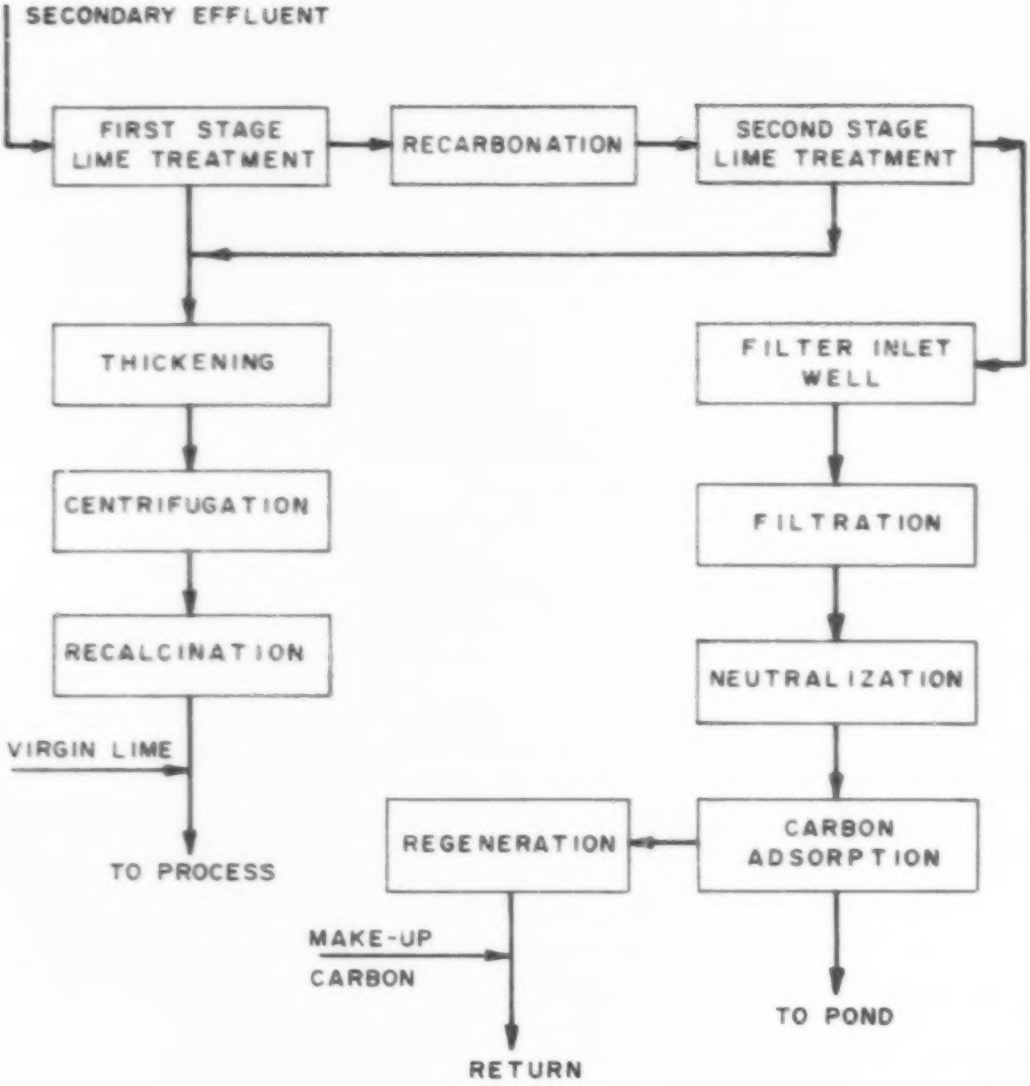

SECONDARY EFFLUENT
FIRST STAGE LIME TREATMENT
RECARBONATION
SECOND STAGE LIME TREATMENT
THICKENING
CENTRIFUGATION
RECALCINATION
VIRGIN LIME
TO PROCESS
FILTER INLET WELL
FILTRATION
NEUTRALIZATION
CARBON ADSORPTION
REGENERATION
MAKE-UP CARBON
RETURN
TO POND

Figure 8-13 Piscataway tertiary treatment plant

and reuse of lime from lime sludges.[6] The test involved the setup of the following experimental components of the system: (1) centrifuge (Sharples P3000) for wet classification, (2) a screw conveyor positioned for loading a truck bed, (3) a truck unloading hopper at the site of a nearby municipal MHF, (4) a temporary belt conveying system for loading the MHF, (5) a thermal disc cooler and water jacketed screw conveyor for cooling and conveying the furnace product, (6) an air classification system for the purpose of separating silica from the furnace product, (7) a hopper for storage of recalcined lime and (8) a slaker for reclaimed lime hydration.

The experimental procedure involved wet classification by centrifuge of all of the sludge produced at the ATTF in the chemical primary. The centrifuge cake was trucked twice daily to another treatment plant (the City of Concord's plant) where an existing MHF was available. The cake was unloaded from the trucks into a receiving hopper, and sludge was conveyed from the hopper to the furnace at a uniform rate by a temporary belt conveyor. Centrifuge cake was recalcined in the MHF, and then the furnace product was cooled and fed to a dry classification system. In the classification system the furnace product was separated into three fractions--an accepts fraction, a coarse rejects fraction and a fine dust fraction. Each fraction was stored in 55 gallon drums, labeled and weighed. The accepts and fine dust drums were then trucked back to the CCCSD's ATTF where the drums were unloaded into an accepts hopper. From the accepts hopper lime was fed via a rotary valve to the slaker, and the slaked lime was then directed back to the chemical clarifier.

Actual recycling of lime was carried out from July 17, 1973 to August 30, 1973, a period of 5 weeks. Only a portion of this period can be considered representative of design conditions. The late July period was characterized by erratic furnace production caused by filling the space between the rabble arms and the hearth bottom ("bedding down"), and certain operational difficulties with the centrifuge and the furnace which affected furnace production adversely. After August 10, 1973, the centrifuge performance deteriorated markedly due to centrifuge wear. The rented centrifuge did not have hardened surfaces and therefore the scroll suffered considerable wear. The end result was that after August 10, calcium carbonate recovery decreased significantly. Therefore, the period of August 1 to 10 best represents design conditions. During this period, 7,110 kg (15,660 lb) of new lime ($Ca(OH)_2$) was used, while 10,199 kg (22,465 lb) of reclaimed lime was returned to the process. Thus, 17,309 kg (38,125 lb) of total lime was used, resulting in a dose of 332 mg/l of calcium hydroxide since the total flow for the 10-day period was 52,235 cu m (13.8 mil gal). This dose corresponded with an operational pH of 11.0.

One artifact was imposed on the experiment that will not be presented in the CCCSD design. The Concord MHF had only wet scrubbing of the stack gasses, whereas the CCCSD design incorporates a dry cyclone prior to the wet scrubber. The solids captured in the cyclone are returned to the MHF for recalcination and reuse in the process. During the tests at Concord, approximately 21 percent of the calcium carbonate fed to the furnace were exhausted with the stack gases. Analysis of the particle size of this material indicates that 59 percent of this material will be captured in a cyclone of CCCSD design. Assuming that a dry cyclone could have been installed during the Concord tests, a total of 12,165 kg (26,823 lb) of lime could have been returned to the process. Under this condition, a total of 70.4 percent of the total dose would derive from reclaimed lime. This value is in excellent agreement with the predicted recycle level of 69 percent.[7,44] Calcium oxide content of the reclaimed lime during the 10-day period averaged 64 percent; the predicted content was 63 percent.[7] The lime slaked readily and the average temperature rise in the AWWA slaking rate test was 36.2 C (range 33.7 to 39.5 C). The temperature rise is lower than the 40 C minimum stipulated for new lime in the AWWA test; however, this merely indicates that the reclaimed lime has a lower CaO content than new lime.

Chemical primary treatment performance during the lime recycling period was superior to a period preceding the lime recycling (Table 8-12). Organic removals improved, as indicated by the BOD_5, SS, TOC and soluble organic carbon measurements. Phosphorus removal markedly improved, and this eliminated the need for supplemental coagulant addition that had previously been necessary for obtaining high phosphorus removals at pH 11.0 or less (see Tables 6-4 and 6-5). The data in Table 8-12 also indicates that the calcium reaction was more complete during lime recycling than prior to it.

Table 8-12. COMPARISON OF PRIMARY SEDIMENTATION PERFORMANCE WITH AND WITHOUT LIME RECYCLE

Constituent (mean value)	With lime recycle[a] pH 11.0 operation[c] $Ca(OH)_2$:335 mg/l			Without lime recycle[b] pH 11.0 operation[c] $Ca(OH)_2$:332 mg/l		
	Raw sewage, mg/l	Chemical primary, mg/l	Percent removed	Raw sewage, mg/l	Chemical primary, mg/l	Percent removed
BOD_5	177	50	72	207	75	64
SS	230	25	89	205	38	81
TOC	145	34	77	126	44	65
Soluble organic carbon (SOC)	27	23	14	24	29	-19
Total phosphorus as P	10.9	0.60	95	11.0	1.45	87
Orthophosphate as P	10.4	0.40	96	10.4	1.04	90
Calcium hardness[d]	101	127	-	67	144	-
Magnesium hardness[d]	106	23		100	25	
Hardness increase[d]		43	+28		+2	-1

[a] July 27 to August 30, 1973, at an average flow of 5,300 cu m/day (1.40 mgd)

[b] July 1 to July 25, 1973, at an average flow of 5,030 cu m/day (1.33 mgd)

[c] No ferric chloride addition

[d] As $CaCO_3$

WASTE SLUDGE INCINERATION

As stated in Section VII, when wet classification is employed to separate the calcium carbonate portion from the other constituents of the lime sludge, one method to dispose of the waste solids in the centrifuge centrate is to thicken and dewater it prior to incineration (Fig. 7-9). Incineration of first-stage centrate cake is similar to incineration of municipal sludge (the purpose is obviously the same, i.e., the destruction of volatile matter to produce an inert ash residue for final disposal). The calorific value of the dewatered centrate cake has been estimated at 5,000 to 5,550 kg-cal per kg of volatile solids (9,000 to 10,000 Btu/lb VS),[37] which is close to that of biological sludges.[16] Wet classification does not normally achieve 100 percent capture of calcium carbonate (Section VII); therefore the centrate from the first stage centrifuge will contain some $CaCO_3$ as well as other inorganic chemicals such as magnesium, phosphorus and iron compounds. Since these compounds are inert, their presence tends to reduce the thermal value of the centrate cake. Moreover, the endothermic decomposition of $CaCO_3$ to CaO further increases the thermal load on the incinerator. A similar situation occurs when conditioning chemicals are added to organic sludges to improve their dewatering characteristics.

As it was shown in Figs. 7-6 and 7-7 and in Table 7-10, the moisture content of the dewatered cake, i.e., the weight of water which must be evaporated prior to combustion, has a decisive influence on both performance and economics of waste sludge incineration. Centrifuge centrate, as biological sludges, is also difficult to dewater. This is indicated in Table 7-11, which shows solids concentrations ranging from only 17 percent TS for centrifugal (second stage) dewatering to 25 percent TS for a filter press operated at 100 psi.

Due to the similarities between centrate from centrifugal classification and biological sludges, it can be assumed that the same incineration systems can be applied to burn both types of dewatered sludges. Sludge incineration practices have been reviewed in Reference 4. Rotary kilns, which are not covered in that report, cannot be used to incinerate municipal sludges due to the relatively high moisture content of the sludge cake.

The presence of lime in the incinerator off-gases might prove troublesome, particularly in fluidized bed reactors. Since the normal operating temperature of the reactor is 760-816 C (1400-1500 F), some of the $CaCO_3$ particles carried with the exhaust gases will be converted to the oxide form. In the sand bed FBR, which is normally used for sludge incineration, exhaust gases are scrubbed in a wet scrubber before being discharged to the atmosphere. It is possible for the CaO to slake in the scrubber thereby causing scaling deposits in this unit (see Section V).

ENERGY CONSIDERATIONS

The Energy Crisis has affected practically every field of activity in the U.S. and in wastewater treatment, its impact has been acutely felt in plants where solids disposal by incineration is practiced. In some instances, the scarcity of fuels has forced the shut down of sludge incinerators and alternate means of sludge disposal had to be found and implemented within a short period of time. Where possible, dewatered cake can be trucked to sanitary dumps. As both the size of the plant and the distance to the dump increases, the amount of fuel consumed in trucking could become an energy consideration on its own and should be compared with the fuel requirements for incineration.

In lime recovery from wastewater sludges, the energy considerations are different than for direct sludge incineration. Since new lime is obtained by calcining of limestone, its production is also a process of high energy consumption. Thus, to evaluate properly the merits of recovering lime from wastewater sludges from an energy standpoint, a comparison in terms of energy requirements should be made between reclaiming spent lime at the wastewater treatment plant and producing new lime from limestone. For a true comparison, the energy used in transporting new lime to the treatment plant should be added to the energy of production to arrive at the overall energy requirements of makeup lime.

Before introducing numerical calculations, it should be pointed out that what follows is not a typical economic comparison. No capital, operating or annual costs are presented in this section, since no attempt has been made to assign a dollar value to the processes examined. Rather, the following paragraphs will try to bring the practice of lime sludge recalcination into a balanced perspective. Incineration processes are highly visible and therefore, an easy target for those concerned with fuel consumption. Costs will be presented in Section XII. To illustrate the energy comparison, materials and heat balances for both a MHF and a FBR will be developed based on the design loadings for the CCCSD's water reclamation plant.[37] Since cake moisture plays a decisive role in the economics of sludge incineration, heat balances have been made at different percentages of solids in the second stage cake (see Fig. 7-9).

Energy Requirements of the MHF

The following conditions have been assumed:

1. Sludge flow rate and composition, as shown in the materials balance, Table 8-13.
2. Excess air for volatiles combustion to be 100 percent of theoretical requirement.
3. Temperature of exhaust gases, 760 C (1400 F), required for afterburning.
4. Fraction of calcined solids passing through the dry cyclone and entering the wet scrubber, 7 percent of the total calcined solids. The remaining portion is discharged from the bottom hearth.

The materials balance, Table 8-13, requires an explanation of the chemical reactions assumed to take place in the furnace. The volatile solids were assumed to be burned completely to carbon dioxide, water, and elemental nitrogen. The conversion of calcium carbonate to calcium oxide was taken as 90 percent complete. Magnesium and ferric hydroxides were assumed to be converted completely to the respective oxides. The combustion products of the auxiliary fuel (natural gas) were assumed to be carbon dioxide and water.

Table 8-13. MATERIALS BALANCE FOR MHF IN RECALCINE MODE

Inputs[a]	kg/hr		lb/hr	
Water		2,838		6,250
Sludge solids:				
Volatiles	596		1,312	
$CaCO_3$	1,873		4,125	
$Mg(OH)_2$	66		145	
$Fe(OH)_2$	15		34	
SiO_2, etc.	288		634	
		2,838		6,250
Natural gas		406		894
Combustion air[b]		16,806		37,018
Total of Inputs		22,888		50,412
Outputs				
Gases[c]:				
H_2O	4,228		9,313	
CO_2	3,053		6,724	
O_2	1,244		2,739	
N_2	2,886		28,384	
		21,411		47,160
Calcined solids				
From bottom hearth[d]				
CaO	878		1,934	
$CaCO_3$	175		384	
Others	321		706	
With off gases[e]		1,374		3,024
CaO	66		146	
$CaCO_3$	13		29	
Others	24		53	
		103		228
Total of Outputs		22,888		50,412

Notes:

[a] All figures taken at 15.6 C (60 F).
[b] Includes excess air.
[c] Taken at 760 C (1400 F).
[d] 93 percent of the total.
[e] 7 percent of the total.

Calculation of the amount of auxiliary fuel required is described in the explanation of Table 8-14, which shows the heat balance. Combustion air requirement was calculated by stoichiometry, using specified excess air of 100 to 10 percent, respectively, for the volatiles and the auxiliary fuel, together with analyses for the volatiles and the fuel. Atmospheric moisture in air was taken as 0.0055 lb of water per lb of dry air. The heat balance shown in Table 8-14 is based on a customary reference temperature of 15.6 C (60 F) and all materials entering the furnace are assumed to enter at that temperature. The term "sensible heat", which is used in Table 8-14, means the heat content above 15.6 C (60 F) in the process stream named. The itimized explanations of Table 8-14, given below, include essential basic data and assumptions used in making the heat and materials balance calculations.

Table 8-14. HEAT BALANCE FOR MHF IN RECALCINE MODE

Item	Heat Requirements:	kcal/hr	Btu/hr
1	To evaporate moisture in sludge	2,704,900	10,734,000
2	Heat loss in calcined solids	214,100	849,600
3	For heat loss by radiation	114,700	455,000
4	For net heat loss in shaft cooling air	66,200	262,600
5	Heats of reaction, $CaCO_3$ & $Mg(OH)_2$ decompositions	759,000	3,011,900
6	Sensible heat at 1,400 F in gases from incineration and calcination	2,171.100	8,615.400
7	Total Heat Requirements	6,030,000	23,928,500
	Heat Inputs:		
8	From volatiles, using low heat value (LHV)	3,050,500	12,105,200
9	From auxiliary fuel (net available at 1,400 F)	2,979.500	11.823.300
10	Total Heat Inputs	6,030,000	23,928,500
11	Gross heat input from auxiliary fuel, based on LHV	4,634,400	18,390,400
12	Sensible heat in auxiliary fuel combustion gases @ 1,400 F	1,654,900	6,567,100
13	Sensible heat at 1,400 F in evaporated water	1,035,600	4,109,400
14	Total sensible heat in furnace off-gases	4,861,600	19,291,900
15	Heat recoverable with waste heat boiler	3,548,900	14,083,000

Item 1, is the heat required to convert 2,838 kg (6,250 lb) of liquid water at 15.6 C (60 F) into water vapor at 760 C (1,400 F). From steam tables this heat requirement per kg of water is 954.3 kcal (1,717.4 Btu/lb).

Item 2, the heat loss in the calcined solids, is for 1,374 kg/hr (3,024 lb/hr) leaving the bottom hearth at 649 C (1,200 F) and 103 kg/hr (228 lb/hr) leaving the off-gases at 760 C (1,400 F). The average specific heat used was 0.2264 Btu/lb/F.

Item 3 is an average of the figures supplied by two manufacturers of the MHF who provided heat balances for a furnace of the size to be used based on their experience.

Item 4 is also an average of the figures supplied by the same two MHF manufacturers. A large amount of air is required to cool the rotating central shaft and rabble arms in a MHF, but 85-90 percent of the heat in this warmed air can be recovered directly by returning it to the furnace as combustion air. Item 4 is the 10-15 percent of the heat in this air stream which is lost by radiation and air leakage.

Item 5 is the heat required for the endothermic chemical reactions:

$$CaCO_3 \longrightarrow CaO + CO_2$$

$$Mg(OH)_2 \longrightarrow MgO + H_2O \text{ (gas)}$$

The heat of reaction for calcium carbonate decomposition is 436.7 kcal/kg (786.8 Btu/lb) of $CaCO_3$; for magnesium hydroxide conversion to the oxide, 347.9 kcal/kg (626.8 Btu/lb) of $Mg(OH)_2$. The heat of conversion of ferric hydroxide to the oxide is negligible because of the small amount present.

Item 6 is the difference in heat content between 15.6 and 760 C (60 and 1,400 F) for the sum of: (1) the gaseous combustion products of the volatile solids, including the 100 percent excess air which was specified to insure complete combustion of the volatiles; (2) the carbon dioxide evolved in calcium carbonate decomposition; and (3) the water vapor evolved in converting magnesium and ferric hydroxides to the respective oxides.

Item 7 is the sum of Items 1 through 6.

Item 8 is the heat generated by combustion of the volatile solids based on a low heat value (LHV) of 5119 kcal/kg (9,223 Btu/lb). This was calculated from a stated high heat value (HHV) for the volatiles of 5550 kcal/kg (10,000 Btu/lb) and the hydrogen content of the volatiles. Composition of the volatiles was taken as:

> Carbon 55.8 percent, Hydrogen 8.2 percent, Oxygen 31.0 percent, Nitrogen 5.0 percent.

Item 9 is the heat required for the sum of the heat inputs to equal the sum of the heat requirements. Numerically, it is equal to Item 7 minus Item 8. The fuel requirement shown in Table 8-13 is obtained by dividing Item 9 by 7,338 kcal/kg (13,221 Btu/lb) which is the calculated net, or effective, heating value per kilogram (pound) of auxiliary fuel at 1,400 F.

Item 10 shows that the sum of the heat inputs equals the total heat requirements.

Item 11, the gross heat input from the auxiliary fuel, is obtained by multiplying the kilograms (pounds) per hour of auxiliary fuel required, as calculated from Item 9, by the LHV for the fuel in kcal/kg (Btu/lb). The definition of heating value of a fuel is the heat evolved per unit weight when the fuel is burned and the combustion products cooled to 15.6 C (60 F). This is exactly equivalent to assuming the fuel to be burned and the heat to be evolved at this temperature. Therefore, in order to obtain the effective heating value of a fuel at a temperature above 15.6 C (60 F), in this case 760 C (1,400 F), the heat required to raise the combustion products to the higher temperature must be subtracted from the published heating value. Published heating values are given in two ways, as the high heat value (HHV), and the low heat value (LHV). The essential difference between HHV and LHV is the heat of condensation at 15.6 C (60 F) of the water formed by combustion of hydrogen in the fuel. The LHV has been used in these combustion calculations because the heat of condensation of water formed in combustion is unavailable in ordinary combustion processes and excluding it allows a clearer presentation of the heat balance. In this case, the fuel was assumed to be natural gas having a LHV of 11,413 kcal/kg (20,564 Btu/lb) and the following analysis:

> Carbon 73.48 percent, hydrogen 23.20 percent, Oxygen 1.10 percent, Nitrogen 2.22 percent.

The calculated net or effective heating value of the gas at 760 C (1,400 F), when burned with a specified 10 percent excess combustion air, is 7338 kcal/kg (13,221 Btu/lb) of gas. Details of this calculation can be found in books dealing with combustion stoichiometry.

Item 12 is the difference in heat content, between 760 C (1,400 F) and 15.6 C (60 F) of the auxiliary fuel combustion products, including the 10 percent of excess combustion air assumed to be used with the fuel. Item 12 is the arithmetic difference between Item 11 and Item 9.

Item 13 is the difference in heat content between 760 and 15.6 C (1,400 F and 60 F) of the water vapor evaporated from the sludge. From steam tables the difference in heat content of water vapor between these two temperatures is 364.9 kcal/kg (657.5 Btu/lb).

Item 14 is the sum of Items 6, 12, and 13. It is the difference in heat content between 760 and 15.6 C (1,400 F and 60 F) of all gases leaving the furnace.

Item 15, the heat potentially recoverable from the furnace off-gases by generating steam in a waste heat boiler, is taken as 73 percent of Item 14. In addition to generating steam, the waste heat boiler will have the useful function of cooling the furnace gases to about 219 C (425 F), thereby greatly reducing the cooling load on the wet scrubber.

Table 8-15 is a summary presentation of the heat balance which may be more readily understood by readers who are unfamiliar with heat balance calculations.

Discussion -

From the heat balance in Table 8-14, it can be seen that of the total heat generated in the furnace, approximately 40 percent is from combustion of sludge volatiles and 60 percent from the auxiliary fuel. In other words, Item 8 is approximately 40 percent of the sum of Items 8 and 11. To evaluate the thermal energy requirement to reburn lime in this way, in comparison with the thermal energy requirement to produce fresh calcium oxide from limestone in a conventional plant, the heat recoverable in a waste heat boiler should be taken into account where a use for steam exists, as in the case of the CCCSD's water reclamation plant. To account for the energy requirement to transport calcium oxide from the producer to the user, the energy requirements of transportation are as follows[46]:

Rail transport - 98 kcal per ton-km (624 Btu per ton-mile)

Truck transport - 542 kcal per ton-km (3,462 Btu per ton-mile).

Table 8-15 SUMMARY OF HEAT BALANCES FOR MHF IN RECALCINE MODE

Gross Heat Inputs	kcal/hr	Btu/hr
Combustion of volatile solids	3,050,500	12,105,200
From auxiliary fuel	4,634,400	18,390,400
Total of Inputs	7,684,900	30,495,600
Heat Accounted for		
To evaporate water at 60 F	1,669,300	6,624,600
Loss by radiation	114,700	455,000
Loss in shaft cooling air	66,200	262,600
Chemical reaction heats, $CaCO_3$ & $Mg(OH)_2$	759,000	3,011,900
Heat loss in calcined solids	214,100	849,600
Heat content above 60 F in off-gases	4,861,600	19,291,900
Total Accounted for	7,685,900	30,495,600

The materials balance (Table 8-13) shows 878 kg (1934 lb) of CaO, equivalent to 0.967 ton, to be recovered with a gross thermal energy input (Item 11, Table 8-14) of 4.6 x 10^6 kcal (18.4 x 10^6 Btu). Heat recoverable with a waste heat boiler from the furnace off-gases amounts to 3.5 x 10^6 kcal (14.1 x 10^6 Btu). The difference between these two heat quantities may be taken as the energy requirement to reburn 0.967 ton of CaO, which is equivalent to 1.1 x 10^6 kcal per ton (4.5 x 10^6 Btu/ton) of reburned CaO.

The thermal energy requirement to produce CaO from limestone, in modern rotary kilns equipped with efficient heat recovery devices, is approximately 1.5 x 10^6 kcal (6 x 10^6 Btu) per ton of CaO.[47,48] The rail line distance from a competitive supplier's plant to Martinez, California, where the CCCSD plant is located, is approximately 550 miles. Using .98 kcal per ton-km (624 Btu per ton-mile) for rail transport, the energy requirement for transport is approximately 86,000 kcal (343,000 Btu) per ton of CaO. Thus, the total thermal energy requirement for a ton of fresh CaO delivered to the CCCSD's water reclamation plant is 1.6 x 10^6 kcal (6.3 x 10^6 Btu) compared with 1.1 x 10^6 kcal (4.5 x 10^6 Btu) for in-plant recalcination.

Incineration of Second Stage Cake -

To illustrate the thermal effect of cake moisture in the incineration of dewatered sludges, materials and heat balances for three different levels of cake moisture are developed in the following paragraphs. Source of sludge in these cases is the thickened centrate from a classification centrifuge (see Fig. 7-9). Since the purpose of this calculation is to show the relationships between cake moisture and heat demand, the example only covers incineration in a MHF. Incineration in a FBR would show similar increases in heat requirements with increased percentages of moisture in the cake.

The heat and materials balances were calculated by the same methods used for dewatered primary sludge, described earlier in this section, taking into account the differences in sludge solids composition. Calculated results are presented for sludge moisture levels of 88, 81 and 70 percent by weight. The two higher values represent moisture contents obtainable in centrifuged cakes; while the lowest value might represent moisture content of a cake produced by a filter press. Compostion of sludge solids, in weight percent, was taken as:

Organics (volatiles)	44.6 percent
$CaCO_3$	15.3
$Ca_5(PO_4)_3(OH)$	17.7
$Mg(OH)_2$	7.4
MgO	3.4
$Fe(OH)_3$	2.1
Fe_2O_3	0.9
SiO_2 and others	8.6
Total	100.0 percent

The fuel value (HHV) of the volatiles was taken as 5,550 kcal/kg (10,000 Btu/lb) and the calculated low heat value (LHV) was taken as 5,119 kcal/kg (9,223 Btu/lb), the same as for the volatiles in the primary sludge. The conservative assumption was made that calcium carbonate, magnesium hydroxide and ferric hydroxide were converted to the respective oxides. The specified gas exit temperature from the furnace was 760 C (1,400 F). The basis for calculating the heat loss in the ash was 93 percent by weight leaving the bottom hearth at 649 C (1,200 F) and 7 percent leaving in the effluent gases at 760 C (1,400 F). This high exit temperature is required to destroy odorous organic compounds. The auxiliary fuel was assumed to be natural gas with a low heating value (LHV) of 11,413 kcal/kg (20,564 Btu/lb). A customary reference temperature of 15.6 C (60 F), was used, with all inputs to the furnace assumed to be at that temperature.

The effect of reducing the sludge moisture content on auxiliary fuel requirement can be seen in the materials balance, Table 8-16. Reducing sludge moisture from 88 to 70 percent reduces the auxiliary fuel requirement by 74.9 percent. For a reduction in moisture from 88 to 81 percent, the reduction in auxiliary fuel is 46 percent.

Heat recoverable in a waste heat boiler attached to the MHF is shown for each of the three moisture levels as Item 10 in Table 8-17, the heat balance tabulation. Item 10 is taken as 73 percent of Item 8.

For situations where by-product steam can be used, examining the net auxiliary fuel requirement to incinerate the sludge may be of interest. If the heat recoverable with the waste heat boiler (Item 10, Table 8-17), is deducted from the gross auxiliary fuel input, (Item 2, Table 8-17), the difference may be taken as the net

Table 8-16. MATERIALS BALANCE FOR MHF AT THREE MOISTURE LEVELS OF SECOND STAGE CAKE

Materials	Cake moisture, % weight					
	88		81		70	
	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr
Inputs:						
Water in sludge cake	9,712	21,391	5,646	12,436	3,090	6,806
Volatile solids in sludge cake	590	1,300	590	1,300	590	1,300
Inorganic solids in sludge cake	734	1,617	734	1,617	734	1,617
Natural gas	1,149	2,531	621	1,367	289	636
Combustion air, total weight	28,991	63,856	19,428	42,793	13,423	29,566
Total of Inputs	41,176	90,695	27,091	59,513	18,126	39,925
Outputs:						
Gases[a]						
H_2O	12,722	28,022	7,509	16,539	4,232	9,321
CO_2	4,381	9,649	2,958	6,515	2,064	4,547
O_2	1,244	2,740	1,044	2,299	918	2,023
N_2	22,212	48,926	14,891	32,802	10,295	22,676
Total for gases	40,559	89,337	26,402	58,155	17,509	38,567
Ash	617	1,358	617	1,358	617	1,358
Total of Outputs	41,176	90,695	27,019	59,513	18,126	39,925

[a] At 760 C (1400 F).

Table 8-17. SUMMARY HEAT BALANCE FOR MHF AT THREE MOISTURE LEVELS OF SECOND STAGE CAKE

Item No.	Item	Cake moisture, % weight					
		88		81		70	
		1000 kcal/hr	1000 Btu/hr	1000 kcal/hr	1000 Btu/hr	1000 kcal/hr	1000 Btu/hr
	Gross Heat Inputs[a]						
1	Volatile solids combustion	3,021	11,990	3,021	11,990	3,021	11,990
2	Natural gas auxiliary fuel	13,116	52,047	7,084	28,111	3,296	13,079
	Total of Inputs	16,137	64,037	10,105	40,101	6,317	25,069
	Heat Accounted For:						
3	To evaporate water at 15.6 C (60 F)	5,713	22,672	3,321	13,181	1,818	7,214
4	Loss by radiation	115	455	115	455	115	455
5	Net loss in shaft cooling air	66	263	66	263	66	263
6	Chemical reaction heats	114	451	114	451	114	451
7	Heat loss in calcined solids	95	375	95	375	95	375
8	Heat content above 15.6 C (60 F) in furnace off gases	10,034	39,821	6,394	25,376	4,109	16,311
9	Total Heat Accounted For	16,137	64,037	10,105	40,101	6,317	25,069
10	Heat recoverable with waste heat boiler:	7,325	29,069	4,668	18,524	3,000	11,907

[a] Based on LHV.

fuel requirement to incinerate the sludge. The values for the three sludge moisture levels are presented in Table 8-18. Table 8-18 shows in another way the fuel saving benefit to be derived from reducing sludge moisture content to the lowest feasible level; at 30 percent moisture, the net heat required to incinerate the sludge cake after heat recovery is negligible.

Table 8-18. AUXILIARY FUEL REQUIREMENTS OF MHF AFTER HEAT RECOVERY

Item	Cake moisture, % weight					
	88		81		70	
	1000 kcal/hr	1000 Btu/hr	1000 kcal/hr	1000 Btu/hr	1000 kcal/hr	1000 Btu/hr
Gross auxiliary fuel input	13,116	52,047	7,084	28,111	3,296	13,079
Recovery in waste heat boiler	7,325	29,069	4,668	18,524	3,001	11,907
Net heat required to incinerate sludge cake	5,790	22,978	2,416	9,587	295	1,172

In the design of CCCSD water reclamation plant, steam generated by the waste heat boilers on the two multiple hearth furnaces is sufficient to supply 94 percent of the average steam requirements of the aeration blowers.[49] Each of three blowers, driven by a 2,750 hp steam turbine, is capable of supplying 1680 cu m/min (60,000 scfm) to the oxidation-nitrification system. Package steam boilers are provided to meet peak steam requirements.

Energy Requirements of the FBR

Materials and heat balances are presented below for the same composition and hourly input rate of dewatered primary lime sludge as was used in calculating the heat and materials balances for the MHF.

As stated earlier in this section, the pellet bed FBR is in use to recover lime from water softening and pulp and paper mill lime sludges. A feature of this flow sheet is the use of the hot gases from the calcining reactor to evaporate water from the incoming sludge, whereby the feed to the calciner is moisture-free. This use of the hot gases from the calciner, therefore, is an important heat recovery feature which is of interest with respect to energy conservation.

Up to now, the pellet bed reactor has not been used on sewage plant sludges. The drying of the sludge takes place at a relatively low temperature, with the gases leaving the dryer at a temperature of 163 C (325 F). Because of this low temperature, there is the possibility that some volatile odorous compounds might not be destroyed and might escape through the final scrubber to the atmosphere.

Calculation of the materials and heat balances for the pellet bed calciner is relatively complex and requires the use of data which were supplied by Dorr-Oliver, Inc.[50] The data supplied by Dorr-Oliver are:

1. 15 percent of dry solids feed to the dryer is lost by carry-over to the scrubber.
2. 15 percent of the calcined product returns to the dryer by carry-over.
3. CaO and MgO in the calcined product carry-over to dryer recombine to form $CaCO_3$ and $Mg(OH)_2$.
4. Radiation heat losses from calciner and dryer are about 5 percent of the heat input to each.
5. Air in-leakage to the dryer (which is under suction) is 60 mole percent of the calciner stack gas flow.
6. Gas temperature leaving calciner 899 C (1650 F).
7. Gas temperature leaving dryer 163 C (325 F).
8. Water is injected into the hot gases leaving the calciner to reduce the temperature to 760 C (1,400 F), to protect the dryer system from too high a temperature.

Other pertinent data are:

1. Heating value (LHV) of sludge volatiles was taken as 5119 kcal/kg (9,223, Btu/lb).
2. Auxiliary fuel was assumed to be natural gas having a LHV of 11,413 kcal/kg (20,564 Btu/lb).
3. Temperatures of streams entering the system was taken as 15.6 C (60 F) except for the combustion and fluidizing air, supplied by blower, which was taken as 54 C (130 F).
4. Recalcination in a pellet bed FBR requires the addition of a small amount, less than 0.3 percent, of soda ash (Na_2CO_3) to cause pellet formation. This small addition was considered negligible in the materials balance.

The calculations for materials and heat balances are shown in Tables 8-19 and 8-20, respectively. It will be apparent that separate but interrelated materials and heat balances must be made for the dryer, the calciner, and gas cooler (water quench to reduce calciner gas temperature from 899 to 760 C (1,650 to 1,400 F)), in order to obtain the overall balances.

Table 8-19. OVERALL MATERIALS BALANCE FOR FLUIDIZED BED CALCINER

Item	To dryer		To gas cooler		To calciner[a]	
	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr
Inputs						
Volatile solids	596	1,313	-	-	507	1,117
$CaCO_3$	1,873	4,125	-	-	1,873	4,125
$Mg(OH)_2$	66	145	-	-	66	145
$Fe(OH)_3$	15	34	-	-	15	34
Inerts	288	634	-	-	288	634
Water in sludge	2,838	6,250	-	-	-	-
Water to gas cooler	-	-	555	1,223	-	-
Natural gas	122	268	-	-	-	-
Theoretical combustion air	6,021	13,263	-	-	-	-
Excess combustion air	4,914	10,823	-	-	-	-
Air in-leakage to dryer	7,348	16,187	-	-	-	-
Subtotals	24,081	53,042	555	1,223	2,749	6,055
Total	24,636 kg/hr (54,265 lb/hr)					

	To scrubber		As product from calciner	
Outputs	kg/hr	lb/hr	kg/hr	lb/hr
N_2	14,003	30,843	-	-
H_2O	4,136	9,111	-	-
CO_2	2,063	4,544	-	-
O_2	2,823	6,219	-	-
Volatile solids	89	197	-	-
$CaCO_3$	281	619	-	-
$Mg(OH)_2$	10	22	-	-
$Fe(OH)_3$	2	5	-	-
Inerts	43	95	245	539
CaO	-	-	892	1,965
MgO	-	-	39	85
Fe_2O_3	-	-	10	21
Subtotals	23,450	51,655	1,186	2,610
Total	24,636 kg/hr (54,265 lb/hr)			

[a] Input to calciner is not additive to dryer input but comes from dryer.

The heat input from auxiliary fuel (LHV) is shown in Table 8-20 as 1,389,000 kcal/hr (5,511,000 Btu/hr). Table 8-19 shows the reburned lime (CaO) produced as 892 kcal/hr (1,965 lb/hr), equivalent to 0.982 ton/hr. The auxiliary fuel requirement per ton of CaO therefore is 1,414,000 kcal/ton (5,612,000 Btu/ton).

Table 8-20. OVERALL HEAT BALANCE FOR FLUIDIZED BED CALCINER

	Btu/hr	kcal/hr
Gross Heat Inputs:		
Volatile Solids	10,289,200	2,592,800
Natural Gas	5,511,200	1,388,300
Combustion and excess air @ 54 C (130 F)	376,000	94,800
Heats of recarbonation and rehydration	500,600	126,200
Total of Inputs	16,677,000	4,202,600
Heat Accounted For:		
Heat of evaporation of 2,838 kg (6,250 lb) water in sludge	6,624,400	1,669,400
Heat of evaporation of 555 kg (1,223 lb) water in gas cooler	1,295,800	326,500
Heat of reaction, $CaCO_3 \rightarrow CaO + CO_2$	3,245,600	817,900
Heat of reaction, hydroxides → oxides	90,900	22,900
Radiation loss from calciner	800,000	201,600
Radiation loss from dryer	600,000	151,200
Sensible heat loss in product	174,500	44,000
Sensible heat loss, solids to scrubber	60,900	15,300
Sensible heat loss, gases to scrubber	3,784,900	953,800
Total	16,677,000	4,202,600

Comparison may be made with the thermal energy requirements given before for one ton of CaO. These were:

1. Reburning in a MHF with credit taken for heat recovery by means of waste heat boiler: 1,122,000 kcal/ton (4,454,000 Btu/ton).

2. Fresh CaO produced in a modern limestone plant in Nevada and transported to Martinez, California: 1,598,000 kcal/ton (6,343,000 Btu/ton).

If the emission of odors is a problem with the pellet bed calciner operating on sewage sludge, reheating the off-gases to 760 C (1,400 F) in an afterburner might be considered a possible solution to the problem. While this could be done physically, the thermal energy requirement would be so large that this approach seems impractical.

In the sand bed FBR installed in Elkhart, Indiana[17], the wet sludge is fed directly to the calciner and all of the recalcined product leaves the reactor in the gas stream. About 85 percent of the calcined lime is separated from the gas stream in a cyclone and the remainder is removed in a wet scrubber. If a waste heat boiler could be successfully operated on gas with this high content of solids, or if the solids content of the gas could be substantially reduced, the same waste heat recovery process might be applied as in the case of the MHF. However, as the Dorr-Oliver Fluo-Solids process now stands, major alterations to it would be required to allow energy recovery by means of a waste heat boiler.

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SECTION IX

AIR QUALITY CONSIDERATIONS

An important problem connected to the operation of sludge incinerators is air pollution. The air pollutants emitted from incinerators that must in general be controlled include:

Particulate matter

Nitrogen oxides (NO_x)

Sulfur oxides (SO_x)

Odorous substances

Trace quantities of metals, pesticides, polychlorinated biphenyls (PCB) and other organic compounds.

The particulate matter released by incinerators burning lime treated sludges includes small amounts of calcium carbonate ($CaCO_3$), calcium oxide (CaO), tricalcium phosphate ($Ca_3(PO_4)_2$), magnesium oxide (MgO) and inert solids. Representative proportions of these constituents which might be expected in the furnace off-gases are given in Table 9-1, where predicted compositions[1] are compared to actual measurements during the CCCSD's Lime Sludge Recycling Study.[2]

A modern sludge incinerator, provided with an adequate scrubbing system and properly operated, is capable of producing acceptable stack emissions of particulate matter, nitrogen oxides, sulfur oxides and odors.[3] The Task Force on sewage sludge incinerators found however, that while the gas emissions are below pollutant levels, most installations did not efficiently control the discharge of particulate matter.

Under the provisions of the Clean Air Act of 1970, the U.S. Environmental Protection Agency (EPA) has implemented standards of performance for municipal sewage treatment plants which would limit the emission of particulate matter from new incinerators burning process sludges.[4] There are also state and local codes covering sludge incinerator emissions and under the Clean Air Act of 1970, state and local codes may not be more lenient but can be more stringent. Typical of these is the regulations of the Bay Area Air Pollution Control District (BAAPCD). The BAAPCD has jurisdiction over nine counties in the San Francisco Bay Area in California. Regulation 2 of the BAAPCD covers particulate emissions in terms of capacity and maximum emission by weight per dry standard cubic foot (DSCF). The weight is corrected for auxiliary fuel consumed in the combustion of sludge.[5]

Table 9-1. SOLIDS COMPOSITION OF LIME FURNACE OFF - GASES, PERCENT

Constituent	Design condition[a]	Measurements during Lime Sludge Recycling Study[b]			
		August 16, 1972		September 11, 1972	
		Test 1	Test 2	Test 1	Test 2
$CaCO_3$	62.5	68.0	59.3	64.6	67.7
CaO	20.5	10.4	20.6	19.8	16.5
$Ca_3(PO_4)_2$	5.5	4.4	4.5	3.7	3.1
MgO	3.5	4.8	4.6	3.4	3.2
Inerts					
SiO_2	-	4.9	4.4	6.6	6.6
Fe_2O_3	-	0.8	0.7	0.6	0.5
Other	-	0.0	0.0	0.0	0.0
Total	8.0	5.7	5.1	7.2	7.1
Unaccounted for	0	6.7	5.9	1.3	2.4

[a] Reference 1.

[b] Reference 2.

In view of the state of flux in which air pollution control regulations **seemed to be at** the time this report was written, it would appear to be in the best interest of each project to design for the most rigid control regulations whether they be federal, state, or local.

Under the present EPA standards, dated March 8, 1970, particulate emissions to the atmosphere would be limited to:[4]

" 1. No more than 70 miligrams per normal cubic meter (mg/$\underline{N}m^3$) undiluted, or 0.031 grains per dry standard cubic foot (gr/dscf).

2. No more than 10 percent opacity."

These same standards do not mention gas pollutant control since the exhaust concentrations of SO_x, NO_x, and CO emitted by a sludge incinerator are below serious pollutant levels.[6] However it is advisable to check state and local regulations for compliance of the gaseous emissions.

In the proposed standards, particulate matter is defined as "any material, other than uncombined water, which exists in a finely divided form as a liquid or solid at standard conditions." Opacity is defined as "the degree to which emissions reduce the transmission of light and obscure the view of an object in the background."

The following paragraphs are included in the standards:[4]

> "Available data indicate that, on the average, uncontrolled multiple-hearth incinerator gases contain about 0.9 gr/dscf of particulate matter. Uncontrolled fluid bed reactor gases contain about 8.0 gr/dscf. For average municipal sewage sludge, these values correspond to about 23 lb/hr in a multiple-hearth unit and about 205 lb/hr in a fluid bed unit. Particulate collection efficiencies of 96.6 to 99.6 percent will be required to meet the standard, based on the above uncontrolled emission rate. Emissions will be on the order of 1.0 lb/hr."
>
> "Existing state or local regulations tend to regulate sludge incinerator emissions through incinerator codes or process weight regulations. The most stringent state or local limit, 0.03 gr/dscf, is based on a test method that is different from the reference methods in that it includes impingers. Many state and local standards are corrected to a reference base of 12 percent carbon dioxide or 6 percent oxygen. Corrections to carbon dioxide or oxygen baselines are not directly related to the sludge incinerator rate because of the high percentage of auxiliary fuel required. In some regulations, the carbon dioxide from fuel burning is subtracted from the total in determinations of compliance."
>
> "For a typical incinerator with a rated dry solids charging rate of 0.5 ton/hr at a gas flow rate of 3,000 dscfm, the proposed standard would allow the incinerator to emit 0.8 lb/hr of particulate matter. The reference process weight regulation would limit emissions to 6.3 lb/hr, based on a charging rate of wet sludge (80 percent water) of 5,000 lb/hr. Dry solids charging rates for new incinerators will range from 0.5 to 4.0 tons/hr, with gas flow rates of 1,000 to 20,000 dscfm."

The production of odors and their control is also a consideration in the operation of sludge incinerators. It has been indicated that the range of temperatures for effective control is 649-816 C (1200-1500 F).[7] Since the MHF operates at 760-982 C (1400-1800 F) in the burning hearths[8] and the FBR operates at a minimum of 760 C (1400 F)[7], both types of incinerators reach operating temperatures that are considered effective in the destruction of odorous substances. Nevertheless, due to certain features of these incineration systems, both may require an afterburner to ensure off-gases deodorization, particularly in those cases where odorous volatile organics are present in the sludge. In the case of a MHF, since raw sludge is introduced to the upper hearth where the drying of sludge occurs before combustion, the temperature of the exit gas from the upper hearth varies from 260 to 593 C (500 to 1100 F)[8] which is below the temperature range for effective odor control. In the pellet bed FBR, the exhaust gases are normally cooled and mixed with the sludge cake (see Section VIII). The preheated mixture then passes through a two-stage cyclonic separator before the off-gases are discharged to atmosphere. Due to the intimate mixing of gas and cake solids, some volatiles may be picked up from the latter and carried over with the exhaust gas. These volatiles are a potential source of odors.

Another important area of concern has been the destruction of pesticides and polychlorinated biphenols (PCB). Both multiple-hearth furnaces with afterburners and fluidized bed reactors will reduce these pollutants to an acceptable level. Research[9] has shown that 99.9 percent of the PCB contained in sewage sludges is destroyed in a multiple-hearth furnace operated at an exit gas temperature of 593 C (1100 F).

The use of a high energy scrubber, such as venturi or impingement type, that is required to achieve the maximum particulate removal from the exit gas stream, will also further reduce the pollutant gases. The total energy required by either of the above types of scrubbers is approximately the same (see Section VIII).

SECTION IX

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SECTION X

MASS EQUILIBRIUM BALANCES OF SOLIDS PROCESSING SYSTEMS BY DIGITAL COMPUTATION

The design and operation of a chemical sludge solids processing system requires the computation of theoretical mass equilibrium values for each component in all process streams of importance. For the solids processing systems such as those shown in Fig. 7-8 and 7-9, manual computation of mass equilibrium values for each component in every process stream is a tedious and time consuming process. Furthermore, new mass equilibrium values for each component need to be calculated each time a change in an operational parameter is made. The importance of having a theoretical model capable of predicting accurate mass equilibrium values for all components in such a complex process can not be overstressed. Rapid calculation of component equilibrium values for various operational modes is important in monitoring the operation of a solids processing system of this type. Also, in the design of this type of system, many different modes of operation must be evaluated before final design decisions are made. A computer program is then needed that can model the system and calculate mass equilibrium values for differing modes of operation.

A computer program, SOLIDS 1A, has been developed to solve (by direct noniterative equations) for the equilibrium mass values of all components in the solids processing sequence shown in Fig. 7-8 and 7-9. The solids processing sequence employs wet classification of primary sludge with recalcination of the recovered sludge solids; with options for second stage dewatering of the centrate from the wet classification step, and incineration of the recovered solids from the dewatering step. Also optional in the solids processing sequence are blowdown of a portion of the recalcination furnace product, dry classification of the recalcination furnace product to selectively purge inert materials from the process, and the ability to recycle furnace wet scrubber water back to the primary. By appropriate adjustment of input data, the program is readily adapted to substitution of vacuum filters or filter presses for the second stage dewatering step; or a Plural Purpose Furnace flow sheet (Fig. 7-8) can be run by inputting high recoveries in the first stage dewatering step. In this event, centrifuges, vacuum filters, or filter presses could be assumed.

In the program, a simplifying assumption is made that solids in the thickener overflows are not returned to the primary stage. In terms of the first stage thickener, such overflows have no impact on any process stream except the primary sludge stream. In terms of the second stage thickener, it is assumed that the "thickener" is more-or-less a holding tank with little or no thickening action taking place so that no stream would return to the primary.

This program was compared to the full-scale test data generated during test work on lime recalcining and recycle at the CCCSD's ATTF. Agreement between prototype and computer output was found to be reasonably good.[1] The program was developed in Fortran IV language for use on the time sharing service of General Electric Information Services, Business Division. It can be easily modified for use on other time share or batch processing services. A listing of the program is given in Section XV. A; symbols used in the program are given in Tables 10-1 through 10-3. If for some reason the design engineer does not have convenient access to a computer, the equations presented in this section and in the program listing in Section XV. B can be used for manual calculations.

Table 10-1. COMMON PREFIXES USED IN PROGRAM "SOLIDS 1A"

Prefix	Meaning
CA	Calcium as Ca
CAC	$CaCO_3$, Calcium carbonate
CAP	$Ca_3(PO_4)_2$, Tri calcium phosphate
CAO	CaO, calcium oxide
CAH	$Ca(OH)_2$, calcium hydroxide
FE	Iron as Fe
FEOH	$Fe(OH)_3$, Ferric Hydroxide
FEO	Fe_2O_3, Ferric oxide
$FECL_3$	$FeCL_3$, Ferric chloride
XMG	Magnesium as Mg
XMGH	$Mg(OH)_2$, Magnesium Hydroxide
XMGO	MgO, Magnesium oxide
ORG	Organics, Volatile Matter
P	Phosphorus as P
SI	SiO_2, Silicon dioxide
AII	Acid insoluble inerts (Other than silica)
XLB	Pounds of
RE	Recovery of
TOTLB	Total pounds of
FR	Fraction of

Table 10-2. COMMON SUFFIXES USED IN PROGRAM "SOLIDS 1A"

Suffix	Meaning
-MGL	In units of mg/l
-IN,-INF	Into the primary flocculation basin
-OUT, -EFF, -EF	Out of the primary sedimentation basin (primary effluent)
-SLG	In the primary sludge
-CAK1	In the first stage centrifuge cake
-CNT1	In the first stage centrifuge centrate
-CAK2	In the second stage centrifuge cake
-CNT2	In the second stage centrifuge centrate
-1	(Recovery) In the first stage centrifuge
-2	(Recovery) In the second stage centrifuge
-WAS	Waste activated (secondary) sludge added to the primary
-SSI, -SSIN	Suspended solids into the primary
-SSO, -SSOUT	Suspended solids out of the primary (in the effluent)
-FP	In the recalcination furnace (product stream)
-FPI	In the incineration furnace (product stream)
-F	(Recovery) In the recalcination furnace
-FI	(Recovery) In the incineration furnace
-CL	(Recovery) In the classifier for recalcined product
-CR	In the classifier reject stream
-RS	In the recycled solids accepts stream back to the primary
-BD	In the blowdown stream from the recalcination furnace
-SE1	In recalcination furnace wet scrubber effluent stream
-SE2	In incineration furnace wet scrubber effluent stream
-1P	In the first pass precipitation (sludge) in the primary
-IND	Dissolved in the primary influent raw sewage
-EFD, EFFD	Dissolved in the primary effluent

Table 10-3. OTHER SYMBOLS USED IN PROGRAM "SOLIDS 1A"

Symbol	Meaning
XMGD	Flow into the primary, mgd
FECL3MGL	Dose of Fe CL_3 to the primary, mg/l
CAHTODOS	Total dose of calcium hydroxide to the primary in units of mg/l
FRBD	Fraction of recalcination furnace stream to blowdown
RECALEFF	Recalcining efficiency of converting Ca CO_3 to Ca O
XMGEFMGL	Magnesium as Mg in primary effluent, mg/l
FRAIISSO	Wt. Fraction of acid insoluble inerts in suspended solids out (effluent)
FRAIISSI	Wt. fraction of acid insoluble inerts in suspended solids into the primary
FRSIWAS	Wt. fraction silicon dioxide in waste activated sludge
FRAIIWAS	Wt. fraction acid insoluble inerts in waste activated sludge
FRVWASIN	Wt. fraction volatile solids in waste activated sludge to the primary
FRVSSIN	Wt. fraction volatile solids in influent suspended solids
FRVSSOUT	Wt. fraction volatile solids in effluent suspended solids
FRSISSI	Wt. fraction silicon dioxide in influent suspended solids
FRSISSO	Wt. fraction silicon dioxide in effluent suspended solids
FRSINEW FRAIINEW FRMGONEW FRCAONEW	**Wt. fraction of stated component in the new (makeup) dry lime solids added to the primary**
CAOTOMGL	Total dose to primary of CAO, in mg/l
CAONEW	Makeup CAO (lime) added to primary
TOTLBNEW	Total new makeup lime added, including impurities, lb
CAONMGL	CAO makeup added to primary, as mg/l
CAORMGL	CAO in recycled solids (RS) stream, as mg/l
CAORSFRA	CAO in recycled solids stream, fraction of total CAO dose

Table 10-3. OTHER SYMBOLS USED IN PROGRAM "SOLIDS 1A" (CONTINUED)

Symbol	Meaning
TOTRE1	Total solids recovery in the first stage centrifuge (wet classification)
TOTRE2	Total solids recovery in the second stage centrifuge (dewatering)
TOTRECL	Total solids recovery in dry classification of recalcined furnace product (recovery in accepts stream)
SEREC	Option code for return or nonreturn of furnace scrubber water to the primary
CLASSIF	Option code for including or excluding dry classification of furnace product
FURNACE	Option code for including or excluding second stage dewatering and incineration of cake in the processing sequence

DESCRIPTION OF PROGRAM

For a given set of operating conditions and unit performances, the equilibrium mass values for the following components are calculated for each process stream:

Organics	(volatile matter)
Calcium carbonate	($CaCO_3$)
Calcium phosphate	($Ca_3(PO_4)_2$)
Magnesium hydroxide	($Mg(OH)_2$)
Magnesium oxide	(MgO)
Ferric hydroxide	($Fe(OH)_3$)
Ferric oxide	(Fe_2O_3)
Silicon dioxide	(SiO_2)
Acid insoluble inerts	(other than SiO_2)
Calcium oxide	(CaO)

The program also calculates the fraction of the total lime dose (as CaO) to the primary contributed by the recycled CaO from the recalcining furnace.

Description of Input

Inputs are required to specify the type of operation desired as described under 1 and 2 below:

1. The type of processing sequence (either Plural Purpose Furnace or ATTF system cases, i.e., dewatering alone or wet classification

followed by dewatering) to be specified is inputted by using the appropriate code for "FURNACE". For ATTF system cases, "FURNACE" = 2.0, while for Plural Purpose Furnace cases, "FURNACE" = 1.0. Also, if a dry classifier is included in the processing sequence, "CLASSIF" = 1.0, while if no dry classifier is wanted, "CLASSIF" = 0.0. If a blowdown stream from the recalcination furnace product is desired (with or without the dry classifier) the appropriate fraction of the furnace product stream to be the blowdown is inputted for "FRBD". If no blowdown is wanted, set "FRBD" = 0.0. The blowdown stream is located ahead of dry classification in the processing sequence. If furnace scrubber effluent water is to be returned to the primary, then set "SEREC" = 1.0. If not, then set "SEREC" = 0.0.

2. The order of process and performance parameters to be inputted is:

   a. Flow rate in MGD as "XMGD".

   b. Waste activated sludge solids added to the primary, in lb/day as "XLBWAS".

   c. Ferric chloride dose to the primary, mg/l as "FECL3MGL".

   d. Total lime dose as $Ca(OH)_2$, in mg/l as "CAHTODOS".

   e. Fraction blowdown as "FRBD".

   f. Recalcining efficiency of converting $CaCO_3$ to CaO, fraction, as "RECALEFF" (as measured on the furnace product).

   g. "FURNACE" as 2.0 or 1.0, and "CLASSIF" as 1.0 or 0.0 as explained previously.

   h. Primary pH as "PH"

   i. "SEREC" as 1.0 or 0.0, as explained previously.

   j. Iron as Fe in the primary influent raw sewage, mg/l, as "FEINFMGL".

   k. Silica dissolved in the primary influent raw sewage, in mg/l of SiO_2, and silica dissolved in the primary effluent in mg/l of SiO_2, as "SIINDMGL", and "SIEFMGL", respectively.

   l. Suspended solids in the primary influent in mg/l as "SSINMGL", and suspended solids in the primary effluent in mg/l as "SSOUTMGL".

   m. Magnesium as Mg in primary influent, mg/l, as "XMGINMGL", and in the effluent (mg/l) as "XMGEFMGL".

   n. Calcium (dissolved and suspended) as Ca in the primary influent, mg/l, as CAINFMGL, and calcium (dissolved and suspended) as Ca in the primary effluent as "CAEFFMGL".

o. Total phosphorus as P, mg/l, in the primary influent as "PINFMGL", and in the effluent as "PEFFMGL".

p. Iron as Fe in the primary effluent, mg/l as "FEEFFMGL".

q. Weight fraction of acid insoluble inerts (inerts other than SiO_2) present in the suspended solids in the effluent as "FRAIISSO", and in the primary influent as "FRAIISI".

r. Weight fraction SiO_2 in waste activated sludge solids as "FRSIWAS", and the weight fraction acid insoluble inerts in the waste activated sludge solids as "FRAIIWAS".

s. The weight fraction of volatile matter in the waste activated sludge solids as "FRVWASIN", in the suspended solids in the influent "FRVSSIN" and in the suspended solids in the effluent as "FRVSSOUT".

t. The weight fraction SiO_2 in the suspended solids in influent as "FRSISSI", and in the effluent as "FRSISSO".

u. The weight fraction of SiO_2, acid insoluble inerts, MgO and CaO in the new makeup lime solids as "FRSINEW", "FRAIINEW", "FRMGONEW", and "FRCAONEW", respectively.

v. Recoveries of all components in the first stage (wet classification) centrifuge cake as fraction recovered:

RECAP1 is recovery of $Ca_3(PO_4)_2)$
RECAC1 is recovery of $CaCO_3$
RESI1 is recovery of SiO_2
REAII1 is recovery of acid insoluble inerts
REXMGH1 is recovery of $Mg(OH)_2$
REXMGO1 is recovery of MgO
REFEOH1 is recovery of $Fe(OH)_3$
REFEO1 is recovery of Fe_2O_3
REORG1 is recovery of organics (volatile matter)

w. Similarly, fractional recoveries for all components in the second stage (dewatering) centrifuge cake are inputted as in "v" above, with the suffix being "2" instead of "1":

RECAP2, RECAC2, RESI2, REAII2, REFEOH2, REFEO2, REORG2, REXMGH2, REXMGO2 are inputted.

x. Fractional recoveries of all components in the recalcination furnace are inputted (suffix is "F" for these components). Furnace recovery means what is recovered as furnace product. Whatever is lost to the furnace dry cyclone is presumed to be recovered in a wet scrubber and the scrubber water returned to the primary.

Recalcination furnace recovery inputs are:

RECAPF, RECACF, RESIF, REAIIF, REFEOHF, REFEOF, REORGF, REXMGHF, REXMGOF.

The recovery of organics and metal hydroxides in the furnaces are intrinsically zero in the program, because all organics are assumed to be combusted, and all metal hydroxides ($Fe(OH)_3$ and $Mg(OH)_2$) are assumed to be converted to metal oxides (Fe_2O_3 and MgO). Hence, the recoveries of the metal oxides in the furnaces will be used for the metal hydroxides because they will exit the furnaces as metal oxides. Also, $CaCO_3$ is converted to CaO in the furnace, and the program uses the $CaCO_3$ recovery and recalcine efficiency to determine the CaO in the furnace product.

y. The fractional recoveries of all components in the incineration furnace are inputted, similar to those for the recalcination furnace. The inputs are given the suffix "FI" for the incineration furnace. Recovery inputs are:

RECAPFI, RECACFI, RESIFI, REAIIFI, REFEOHFI, REFEOFI, REORGFI, REXMGHFI, REXMGOFI.

Again, recoveries are defined as in the case discussed above for the recalcination furnace, and inputs for recoveries of organics and metal hydroxides will be zero.

z. The fractional recoveries of compounds in the dry classifier for recalcined product are inputted last. The fractional recovery is defined as the mass of material accepted and recycled back to the primary divided by the total mass of material classified. Classifier rejects are assumed to be discarded. Again, recoveries of organics, and metal hydroxides are inputted as zero because none of these appear in the recalcined product to be classified.

Inputs are given the suffix "CL", as:

RECAPCL, RECACCL, RESICL, REAIICL, REFEOHCL, RECAOCL, REFEOCL, REORGCL, REXMGHCL, REXMGOCL.

The recovery of CaO is inputted here because it is present in the recalcination furnace product, as a separate compound, along with the remaining $CaCO_3$ that was not recalcined. If no dry classifier is to be used, input the recoveries of all components (except organics, $Mg(OH)_2$ and $Fe(OH)_3$, which are zero) in the classifier as 1.0 (total recovery).

Input Data Format

The input data is arranged into three data files (e.g., three separate magnetic cards, three sets of punch cards, etc.). The first input file, which is called "DAT1" simply lists a line number followed by the input terms. There are two lines on the first (DAT1) file. Line numbers have been assigned arbitrarily. The first input file is shown in Table 10-4.

Table 10-4. FORMAT FOR DATA FILE "DAT1"

Input parameters in computer code	Description	Sample file list
L,XMGD,XLBWASIN,FECL3MGL,CAHTODOS, FRBD,RECALEFF	File list no., primary flow, lb/day waste activated sludge added; $FeCL_3$ dose, total dose of lime as mg/l of $Ca(OH)_2$, fraction blowdown, recalcination efficiency	110,30.0,9746.0,14.0,400.0, 0.0,0.95
L,FURNACE,CLASSIF,PH,SEREC,FEINFMGL, SIINDMGL,SIEFDMGL	File list no., furnace option code, classifier option code, primary pH, furnace scrubber water return option, Iron as mg/l Fe in raw sewage, dissolved silica as mg/l SiO_2 in raw sewage and primary effluent	115,2.0,0.0,11.0,1.0,0.0, 0.0,0.0

A sample of the numbers which might be used for a two stage centrifuge-furnace case with dry classification of the recalcined product is shown (case 100, Section XV. B). The format is in the "variable specification", so that any floating point format can be used for any of the input numbers. The first number on each line is the line number required to construct a data file list by the time share service.

The second group and third groups of input data, which the program recognizes as files "DAT2" and "DAT3" are shown in Tables 10-5 and 10-6.

It is important to input recovery values for all components, even those that are intrinsically zero (as recovery of organics or metal hydroxides in the furnaces or classifier - in these cases, the input values would be 0.0). Also, in the case that any component will not be present in the primary influent or in any stream added to the primary (hence, this component will not be in any of the process streams printed out), it is important to input hypothetical recovery values for that component in either the first stage or second stage centrifuge to prevent division by zero in certain equations. In fact, if ever the recoveries in both the first and second stage centrifuge are inputted as zero for a particular component, division by zero results, causing the calculated amount of that component present in the primary sludge to be infinite.

Outputs

The program prints out calculated equilibrium values as well as some specified recoveries, performance parameters, and operational conditions. Output for the cases evaluated for this report are shown in Section XV. B.

Table 10-5. FORMAT FOR DATA FILE "DAT2"

Input parameters in computer code	Description	Sample file list
L,SSINMGL,SSOUTMGL,XMGINMGL,XMGEFMGL,CAINFMGL,CAEFFMGL	File list no., influent primary suspended solids (mg/l); effluent primary suspended solids (mg/l); magnesium as Mg in the primary influent (mg/l); primary effluent total Mg as Mg (mg/l); primary influent calcium as Ca (mg/l); Primary effluent total calcium as Ca (mg/l)	131,240.0,26.0,22.3,8.74,30.0,60.0
L,PINFMGL,PEFFMGL,FEEFFMGL,FARIISSO,FRAIISSI	File list no., influent total P as P (mg/l); primary effluent total P (mg/l); primary effluent total Fe as Fe (mg/l); weight fractions of: acid insoluble inerts in effluent suspended solids, acid insoluble inerts in influent suspended solids	132,10.0,0.68,0.0,0.0024,0.0024
L,FRSIWAS,FRAIIWAS,FRVWASIN,FRVSSIN,FRVSSOUT	File list no., weight fractions of: SiO_2 in waste activated sludge, acid insoluble inerts in waste activated sludge, volatile matter in waste activated sludge, volatile matter in influent suspended solids, volatile matter in effluent suspended solids	141,0.035,0.0024,0.80,0.80,0.80
L,FRSISSI,FRSISSO,FRSINEW,FRAIINEW,FRMGONEW,FRCAONEW	File list no., weight fractions of: SiO_2 in influent suspended solids, SiO_2 in effluent suspended solids, SiO_2 in new makeup lime, acid insoluble inerts in makeup lime, MgO in makeup lime, CaO in makeup lime	151,0.035,0.035,0.027,0.0096,0.07,0.89

Table 10-6. FORMAT FOR DATA FILE "DAT3"

Input parameters in computer code	Description	Sample file list
	Recoveries in the first stage centrifuge of:	
L,RECAP1,RECAC1,RESI1,REAII1	File list no., $Ca_3(PO_4)_2$, $CaCO_3$, SiO_2, Acid Insol. Inerts	161,0.20,0.825,0.90,0.77
L,REXMGH1,REXMGO1,REFEOH1,REFEO1,REORG1	File list no., $Mg(OH)_2$, MgO, $Fe(OH)_3$, Fe_2O_3, Organics	171,0.27,0.27,0.30,0.30,0.40
	Recoveries in the second stage centrifuge of:	
L,RECAP2,RECAC2,RESI2,REAII2,REFEOH2	File list no., $Ca_3(PO_4)_2$, $CaCO_3$, SiO_2, Acid Insol. Inerts, $Fe(OH)_3$	181,0.90,0.99,0.97,0.81,0.90
L,REFEO2,REORG2,REXMGH2,REXMGO2	File list no., Fe_2O_3, Organics, $Mg(OH)_2$, MgO	182,0.90,0.78,0.90,0.90
	Recoveries in the recalcination furnace of:	
L,RECAPF,RECACF,RESIF,REAIIF,REFEOHF	File list no., $Ca_3(PO_4)_2$, $CaCO_3$, SiO_2, Acid Insol. Inerts, $Fe(OH)_3$	191,0.94,0.93,0.98,0.87,0.0
L,REFEOF,REORGF,REXMGHF,REXMGOF	File list no., Fe_2O_3, Organics, $Mg(OH)_2$, MgO	192,0.95,0.0,0.0,0.92
	Recoveries in the incineration furnace of:	
L,RECAPFI,RECACFI,RESIFI,REAIIFI,REFEOHFI	File list no., $Ca_3(PO_4)_2$, $CaCO_3$, SiO_2, Acid Insol. Inerts, $Fe(OH)_3$	201,0.94,0.93,0.98,0.87,0.0
L,REFEOFI,REORGFI,REXMGHFI,REXMGOFI	File list no., Fe_2O_3, Organics, $Mg(OH)_2$, MgO	202,0.95,0.0,0.0,0.92
	Recoveries in the dry classifier of:	
L,RECAPCL,RECACCL,RESICL,REAIICL,REFEOHCL,RECAOCL	File list no., $Ca_3(PO_4)_2$, $CaCO_3$, SiO_2, Acid Insol. Inerts, $Fe(OH)_3$, CaO	211,0.957,0.984,0.761,0.929,0.0,0.981
L,REFEOCL,REORGCL,REXMGHCL,REXMGOCL	File list no., Fe_2O_3, Organics, $Mg(OH)_2$, MgO	212,0.864,0.0,0.0,0.966

The first output line is for primary operating pH, primary flow (MGD), and lime use as calcium oxide. The total lime dose required for primary operation at pH 11.0 is printed (this was an input value). Calculated values for the doses (mg/l) of required makeup lime and recovered recalcined lime are printed also on the first line, as well as the fraction of the total dose contributed by the recovered lime (CaO).

The second output line simply prints out the inputted values for the dose of $FeCl_3$ (mg/l) used in the primary and the amount of waste biological sludge added to the primary.

The third output line prints out the specified fraction of recalcination furnace product to be blown down and the specified efficiency of recalcination (fractional conversion) of $CaCO_3$ to CaO, as measured in the furnace product.

The fourth output lists the weight fractions of SiO_2, acid insoluble inerts, MgO and CaO specified in the new (makeup) lime solids added to the primary.

The fifth output line lists the primary influent compositon (mg/l) of suspended solids, magnesium, calcium, phosphorus, SiO_2, acid insoluble inerts, and iron. The suspended solids composition in the raw sewage does not include the waste activated sludge solids added to the primary. The SiO_2 composition, however, for program calculation reasons, does include the SiO_2 present in the raw sewage suspended solids, the waste activated sludge solids, and the makeup lime. Similarly, the acid insoluble inerts includes what is present in the raw sewage suspended solids, the added waste activated sludge solids, and the new added makeup lime. The magnesium, calcium and phosphorus composition values are based on total magnesium, calcium and phosphorus (as the elements) in the raw sewage.

The sixth output line lists the primary effluent composition values (mg/l) specified for total calcium, magnesium, phosphorus and iron (Fe) as the elements, as well as composition values for suspended solids, SiO_2 and acid insoluble inerts. The SiO_2 and acid insoluble inerts values are calculated from the inputted weight fraction of each component present in the effluent suspended solids.

The next several outputs are for the amount of each component present in each process stream. The "First Pass Precipitation" stream is the amount of each component that would precipitate in the primary sludge if the primary was isolated and received only raw sewage and chemical addition streams; that is, there are no return streams to the primary sedimentation tank from solids processing operations. For the purpose of this calculation, the fraction of lime that comes from the recalcined product is assumed to be 100 percent CaO. Note that CaO and Fe_2O_3 will always be zero in this stream, because CaO added reacts to form $CaCO_3$ and $FeCl_3$ added precipitates as $Fe(OH)_3$ and not Fe_2O_3.

The "Primary Sludge" component output includes the materials in the first pass precipitation stream plus all materials recycled to the primary from the following streams: recycled (recalcined) solids, centrate recycle (second stage or first stage, depending on what mode of operation is desired) to the primary, and furnace wet scrubber water returned to the primary. Note again it is assumed that there will never be any CaO present in the primary sludge (it all precipitates as $CaCO_3$).

The "First Stage Cake" stream is calculated by using the recoveries inputted for each component in the first stage centrifuge (wet classification) step. Note that any separation process (centrifuge, filter press, vacuum filter, etc.) could be used for the first stage dewatering step.

The "First Stage Centrate" stream is the portion of the primary sludge not recovered in the first stage dewatering step.

The "Recalcination Furnace Product" stream is the mass of each component recovered from the recalcination of the first stage cake stream. The recovered furnace product is calculated by subtracting from the furnace feed the portion of material not recovered in the furnace. This portion is calculated from the inputted recoveries for each component.

The "Recalcination Furnace Wet Scrubber" stream is, as explained before, the unrecovered portion of material in the recalcination furnace which is returned to the primary via wet scrubber water.

The "Recycled Solids Accepts" stream is the portion of recalcination furnace product, minus any blowdown (if specified), which has been accepted by the dry classification step. If no dry classification step is specified, the recycled solids stream is the recalcination furnace product stream, less any blowdown.

The "Second Stage Cake" component stream is calculated from inputted component recoveries for the second stage centrifuge (dewatering step). The second stage cake is that portion of the first stage centrate solids (from wet classification) which is recovered by dewatering.

The "Second Stage Centrate" is the portion of the first stage centrate not recovered in the dewatering step, and therefore recycled back to the primary.

The "Incineration Furnace Waste Ash" stream is the portion of the second stage cake which is recovered (not lost to the incineration furnace wet scrubber) in the incineration furnace product. This ash product is disposed to waste. Note that the incineration furnace is run at a lower temperature than the recalcination furnace, so it is assumed that no $CaCO_3$ is recalcined to CaO; however, metal hydroxides are assumed to be converted to the oxides.

The "Incineration Furnace Wet Scrubber" stream is the portion of unrecovered material in the incineration furnace, which is captured by a final wet scrubber and returned to the primary.

The "Recalcination Furnace Blowdown" stream is the portion of the furnace product that is to be wasted (or "blown down") to purge the system of inerts. This stream is printed out only if there is a blowdown fraction specified.

The "Classifier Rejects Stream" is the material rejected by the dry classifier and disposed of as waste. This stream is shown only if there is a dry classifier for recalcined furnace product.

The final output group lists the inputted recoveries for each component in the first stage (wet classification) centrifuge, recalcination furnace, second stage (dewatering) centrifuge, incineration furnace and dry classifier. The calculated total recovery of solids in the wet classification, dewatering, and dry classification steps is shown also.

DERIVATION OF EQUATIONS AND PROGRAM MECHANICS

The equations used to solve for the equilibrium mass values of each component present in the primary sludge are the key equations. Once the total composition of the primary sludge is known, the composition of every other process stream can be easily obtained by using the component recovery values inputted for the first and second stage centrifuges (wet classification and dewatering steps), the recalcination and incineration furnaces, and the dry classifier. The chemical reactions producing sludge precipitates have been described in Section VI.

Metal Hydroxides and Organics

Basically, the amount of a component precipitated in the primary sludge is the summation of the amounts of that component present in all the streams, or chemicals returned or fed to the primary; less the amount of that component leaving in the primary effluent. The ferric hydroxide ($Fe(OH)_3$) precipitated in the primary sludge from the chemical addition of ferric chloride, plus the ferric hydroxide returned to the primary from the recycled centrate, plus the Fe in the raw sewage (taken as $Fe(OH)_3$), minus the ferric hydroxide leaving in the effluent; equals the equilibrium amount of $Fe(OH)_3$ present in the primary sludge for a given mode of operation. Recall, FEOHSLG is the symbol for the equilibrium mass value of $Fe(OH)_3$ in the primary sludge. In terms of the program symbols (Tables 10-1 to 10-3) and Fortran algebra the equation would be:

```
FEOHSLG =  (FECL3) * (107./162.5) + FEOHCNT2
        -  (FEEFF) * (107./56.) + (FEINFMGL)
        *  (XMGD) * (8.33) * (107./56.)                    (1)
```

The conversion factors of FECL3 and FEEFF in equation (1) convert ferric chloride and elemental iron (Fe) to equivalent $Fe(OH)_3$.

There are two unknowns in equation (1); FEOHSLG and FEOHCNT2. Therefore, in order to solve the equation, the number of unknowns must be reduced to one. To accomplish this, the FEOHCNT2 ($Fe(OH)_3$ in the recycled centrate) can be related to FEOHSLG (the $Fe(OH)_3$ in the primary sludge at equilibrium) by applying the recovery factors for $Fe(OH)_3$ in the first and second stage centrifuge operations. Thus:

```
FEOHCNT2 = (1.-REFEOH1) * (1.-REFEOH2) * (FEOHSLG)         (2)
```

Recall, REFEOH1 is the recovery of $Fe(OH)_3$ in the first stage centrifuge, so (1.-REFEOH1) is the fraction of the $Fe(OH)_3$ in the primary sludge that appears in the first stage centrate. Likewise, (1.-REFEOH2) is the fraction of the $Fe(OH)_3$ in the first stage centrate that is not recovered in the second stage centrifuge (dewatering step) and appears in the second stage centrate. Hence, solving the original equation for the equilibrium value of $Fe(OH)_3$ in the primary sludge gives:

```
FEOHSLG =  ((FECL3) * (107./162.5) + (FEINFMGL) * (107./56.)
         *  (XMGD) * (8.33) - (FEEFF) * (107./56))
         /  (1.-(1.-REFEOH2) * (1.-REFEOH1))                    (3)
```

All the terms on the right hand side of the equation are known, allowing a simple algebraic solution for FEOHSLG.

Once the value of FEOHSLG is obtained, the amount of $Fe(OH)_3$ in the first stage cake (FEOHCAK1) can be obtained by multiplying FEOHSLG by the recovery of $Fe(OH)_3$ in the first stage centrifuge (REFEOH1) as follows:

```
FEOHCAK1 = (FEOHSLG) * (REFEOH1)                                (4)
```

Similarly the $Fe(OH)_3$ in the first stage centrate would be:

```
FEOHCNT1 = FEOHSLG * (1.-REFEOH1)                               (5)
```

The $Fe(OH)_3$ in the second stage cake is found from:

```
FEOHCAK2 = (FEOHCNT1) * (REFEOH2)                               (6)
```

As mentioned before, there is no $Fe(OH)_3$ in either of the furnace products, or in the furnace wet scrubber water streams which are returned to the primary.

A similar set of equations can be used to solve for $Mg(OH)_2$ and organics in the various process streams (see Section XV. A). Recall, there is no $Mg(OH)_2$ or organics in either of the furnace products, or in the furnace scrubber water streams. Magnesium hydroxide entering the primary is composed of that $Mg(OH)_2$ present in the recycle centrate stream plus that precipitated from reactions of magnesium ions present in the raw sewage. The organics coming into the primary are from the volatile portion of the influent suspended solids and added waste activated sludge solids, plus the organics in the recycled centrate stream.

Metal Oxides

The solution for the equilibrium values of metal oxides (Fe_2O_3 or MgO) in the primary sludge uses basically the same approach as that for the metal hydroxides except that more streams are involved in the balance. For instance, the MgO present in the primary sludge at equilibrium is composed of MgO from the following sources: (1) Recycled recalcined solids stream; (2) Trace amount (as impurity) in new makeup CaO added; (3) Wet scrubber water stream from recalcining furnace; (4) Wet scrubber water stream from incineration furnace;

and (5) Recycled centrate stream. The metal hydroxides that are converted to metal oxides in each furnace must be included as part of the recycled metal oxide streams. Hence, there is more metal oxide in the furnace product than in the feed because of the metal hydroxide converted to oxide in the furnace. A material balance for the MgO in the primary sludge (XMGOSLG), is shown in Table 10-7. The sources contributing to the equilibrium value of MgO in the primary sludge are listed, with the corresponding equations used in the program to describe the MgO source.

Table 10-7. MATERIAL BALANCE DESCRIPTION FOR MAGNESIUM OXIDE IN THE PRIMARY SLUDGE

Sources contributing to primary sludge equilibrium MgO	Program equation for MgO source
	XMGOSLG = the sum of the following terms:
MgO in recycled solids from conversion of $Mg(OH)_2$ to MgO in the recalcining furnace	(XMGHCAK1) * (REXMGOF) * (1.-FRBD) * (REXMGOCL) * (40./58.3)
MgO in recalcining furnace scrubber water due to $Mg(OH)_2$ conversion to MgO and captured by the wet scrubber	(1.-REXMGOF) * (XMGHCAK1) * (40./58.3)
MgO in incineration furnace scrubber water due to $Mg(OH)_2$ conversion to MgO in the furnace and captured by the wet scrubber	(1.-REXMGOFI) * (XMGHCAK2) * (40./58.3)
MgO as impurities in new lime	XMGO NEW
MgO from second stage centrate recycle	XMGOSLG * (1.-REXMGO1) * (1.-REXMGO2)
MgO from recycled solids stream that was present in the first stage cake as MgO	XMGOSLG * (REXMGO1) * (REXMGOF) * (REXMGOCL) * (1.-FRBD)
MgO from the recalcination furnace wet scrubber (this is MgO that was present as MgO in the first stage cake but not recovered in the furnace)	(XMGOSLG) * (1.-REXMGOF) * (REXMGO1)
MgO from the incineration furnace wet scrubber (this is MgO that was present as MgO in the second stage cake but not recovered in the furnace)	(XMGOSLG) * (1.-REXMGO1) * (REXMGO2) * (1.-REXMGOFI)

The equations in the right hand side of Table 10-7 can be summed up, and solved for XMGOSLG, the equilibrium value for MgO in the primary sludge. This results in:

```
XMGOSLG = ((XMGHCAK1) * (REXMGOF) * (1.-FRBD)
          * (REXMGOCL) * (40./58.3) + (1.-REXMGOF)
          * (XMGHCAK1) * (40./58.3) + (XMGONEW)
          + (1.-REXMGOFI) * (XMGHCAK2) * (40./58.3))
          / (1.-REXMGO1) * (1.-REXMGO2) * (1.-FRBD)
          - (1.-[illegible]EXMGOF) * (REXMGO1) - (1.-REXMGOF)
          * (REXMGO1) - (1.-REXMGO1) * (REXMGO2)
          * (1.-REXMGOFI)                                  (7)
```

This is the approach used to solve for the equilibrium mass values for all quantities in the primary sludge. The equations can be examined in the program listing in Section XV. A. The equation for MgO was used as an example because it illustrates most of the concepts employed in solving for the mass equilibrium values of each component.

Inert Materials

The inert components represented in the program are silicon dioxide (SiO_2) and acid insoluble inerts (inerts other than SiO_2). The inerts come into the primary as part of the suspended solids and waste activated sludge solids, as impurities in new (makeup) lime added to the primary, and in the case of silica, as dissolved material in the raw sewage. The method of solving for the equilibrium values of SiO_2 and acid insoluble inerts in the primary sludge is similar to that for MgO. However, neither of the two inert components have hydroxide forms, and it has been assumed that they behave as inerts in the furnace.

Tri Calcium Phosphate

Tri calcium phosphate ($Ca_3(PO_4)_2$) is assumed to behave as an inert material during recalcination or incineration, and its equilibrium value in the primary sludge is calculated by a similar approach as for the inerts and metal oxides.

Calcium Carbonate and Calcium Oxide

The calcium carbonate that precipitates in the primary sludge is calculated by adding the calcium (as calcium carbonate) in the raw influent sewage, the calcium oxide (as calcium carbonate) in the total lime (makeup plus recycle), the calcium carbonate from the centrate recycle, the calcium carbonate from the recycled solids from the recalcine-classification operation, and the calcium carbonate returned to the primary in the wet scrubber water streams from both furnaces; minus the amount of calcium precipitated by the phosphorus (as $Ca_3(PO_4)_2$) which is removed in the primary, and minus the calcium (as calcium carbonate) leaving in the primary effluent. In the recalcining furnace, if the recalcination efficiency is less than one, then some $CaCO_3$ will appear in the furnace product. The recovery of calcium oxide in the recalcining furnace is assumed to be equal to the recovery of $CaCO_3$, since $CaCO_3$ is converted to CaO in the recalcining furnace. Recalcine efficiency as a fraction is defined in terms of the split between CaO and $CaCO_3$ in the furnace products as follows:

RECALEFF = CAOFP * (100./56.) / (CAOFP * (100./56.) + (CACFP))

The CaO picked up by the wet scrubber is assumed to react to form $CaCO_3$. Hence the $CaCO_3$ not recalcined in the furnace but lost out the stack, and the CaO lost out the stack, are both treated as $CaCO_3$ in computing the loss of non-phosphorus calcium to the furnace wet scrubber water.

It is assumed that there is no recalcination of $CaCO_3$ to CaO in the incinerator furnace since this furnace is operated at a temperature lower than the conversion temperature (see Section VIII).

The total lime dose required for a certain mode of operation is inputted to the program as $Ca(OH)_2$, mg/l. The program converts this dose to equivalent CaO for computations.

The amount of each component that would precipitate in a once through primary operation is calculated by the program. In the case of $CaCO_3$, the total lime dose (recycled plus makeup) would be considered as a chemical addition stream to the primary in order to determine the amount of $CaCO_3$ that would precipitate in a first pass situation. The amount of calcium (as calcium carbonate) in the raw sewage plus the calcium carbonate precipitated from total lime additions, minus the calcium (as $CaCO_3$) lost to the effluent and to the precipitated $Ca_3(PO_4)_2$, gives the calcium carbonate in the first pass precipitation.

MATERIAL BALANCES FOR SEVERAL CASES

Several cases were run on **the computer**, simulating various process modes of operation. The cases were constructed using data on unit processes presented in earlier sections of this report as well as other reports on the ATTF test work (1, 2). Table 10-8 summarizes the process description for each case. Most runs were made simulating pH 11.0 operation, with a primary flow rate of 1.31 cu m/sec (30 mgd), 400 mg/l of $Ca(OH)_2$ as a total lime dose, and 14 mg/l of $FeCl_3$ added to the primary. The processing sequence was varied to simulate both Plural Purpose Furnace and ATTF System cases, employing one stage (high recovery) or two stage (wet classification and dewatering) processing of primary sludge. Other process options included or excluded in the cases were dry classification and/or blowdown of recalcined furnace product.

Table 10-9 lists some of the important solids balance comparisons for various solids processing cases. At pH 11.0, with both wet classification and dewatering of primary sludge solids, comparisons were made using a solid bowl centrifuge for wet classification and either a solid bowl centrifuge, vacuum filter, or filter press for the second stage dewatering step. The solids processing sequence employed for each case is described in Table 10-8 (100, 101 and 102).

The use of pressure filtration for the second stage dewatering step has an advantage over a solid bowl centrifuge or vacuum filter in that the amount of sludge produced in the primary is slightly less, because less solids are recycled back to the primary from the dewatering step. The amount of makeup lime required for each case is not significantly different. Pressure filtration results in a significantly drier second stage cake than either vacuum filtration or centrifugation. This property results in less moisture to be evaporated (Table 7-11) and less energy requirement for the second stage MHF (Table 8-18).

In Plural Purpose Furnace cases 106, 114 and 116, dry classification as well as a 20 percent blowdown of furnace product was included. The blowdown was included to keep the amount of silica produced in the primary as low as possible without wasting too much CaO. Fig. 10-1 shows the effect of blowdown for a Plural Purpose Furnace case upon recovery of CaO. The optimum operating blowdown will depend on the economics for each situation. Fig. 10-2 shows the effect of furnace blowdown on primary sludge production. The amount of sludge

Table 10-8. SOLIDS PROCESSING SEQUENCE OPTIONS FOR VARIOUS CASES

Case no.[a]	pH	$Ca(OH)_2$ dose, mg/l	$FeCl_3$ dose, mg/l	Processing options					
				Wet classification of primary sludge	Recalcination	Dry classification of recalcined ash	Blowdown, percent	Dewatering of first stage centrate	Incineration of second stage cake
100[b]	11.0	400	14.0	Solid bowl centrifuge	MHF	Yes	0	Solid bowl centrifuge	MHF
101[b]	11.0	400	14.0	Solid bowl centrifuge	MHF	Yes	0	Vacuum filter	MHF
102[b]	11.0	400	14.0	Solid bowl centrifuge	MHF	Yes	0	Pressure filter press	MHF
106[c]	11.0	400	14.0	Solid bowl centrifuge	MHF	Yes	20	No	None
114[c]	11.0	400	14.0	Vacuum filter	MHF	Yes	20	No	None
116[c]	11.0	400	14.0	Filter press	MHF	Yes	20	No	None
117[b]	11.0	400	14.0	Solid bowl centrifuge	MHF	No	0	Solid bowl centrifuge	MHF
[illegible]0[b]	11.0	400	14.0	Solid bowl centrifuge	MHF	No	28	Solid bowl centrifuge	MHF
121[b]	10.2	289	24.0	Solid bowl centrifuge	MHF	Yes	0	Solid bowl centrifuge	MHF
122[b]	11.5	500	0.0	Solid bowl centrifuge	MHF	Yes	0	Solid bowl centrifuge	MHF
113[c]	11.0	400	14.0	Vacuum filter	MHF	Yes	0	No	None
112[c]	11.0	400	14.0	Solid bowl centrifuge	MHF	Yes	100	No	None

[a] All plant flows at 1.31 cu m/sec (30 mgd)

[b] ATTF System Case - two-stage dewatering

[c] Plural Purpose Furnace Case - single stage dewatering

Table 10-9. MATERIAL BALANCE COMPARISONS FOR VARIOUS SOLIDS PROCESSES CASES

Case no.	pH	Primary sludge production, kg per day (lb per day)	First stage cake to recalcining		Recycled solids from recalcining,[a] kg per day (lb per day)	Recycled solids from dewatering step, kg per day (lb per day)	Recycled solids from furnace wet scrubbers, kg per day (lb per day)	Second stage cake to incineration		Furnace ash to disposal kg per day (lb per day)	Makeup CaO		Dry classifier rejects, kg per day (lb per day)	Recalcination furnace blowdown stream, kg per day (lb per day)
			kg per day (lb per day)	Percent TS				kg per day (lb per day)	Percent TS		CaO,[b] kg per day (lb per day)	Percent of total CaO dose		
100	11.0	100,940 (224,312)	62,977 (139,950)	58	29,962 (66,583)	4,837 (10,749)	4,844 (10,766)	33,126 (73,614)	17	19,433 (43,186)	12,786 (28,413)	38.0	1,602 (3,560)	0 (0)
101	11.0	98,043 (217,875)	62,104 (138,011)	58	29,986 (66,636)	2,156 (4,792)	4,805 (10,679)	33,782 (75,073)	20	19,071 (42,382)	12,583 (27,963)	37.0	1,598 (3,553)	0 (0)
102	11.0	96,036 (213,414)	61,653 (135,945)	58	29,579 (65,733)	348 (775)	4,793 (10,650)	34,782 (76,694)	25	19,486 (43,302)	12,786 (28,413)	38.0	1,575 (3,500)	0 (0)
106	11.0	132,036 (293,415)	126,204 (278,281)	24	56,290 (125,089)	6,810 (15,134)	6,828 (15,174)	0 (0)	-	0 (0)	13,494 (29,988)	40.0	17,364 (38,587)	14,730 (32,735)
114	11.0	131,817 (292,928)	126,204 (278,281)	28	56,290 (125,089)	6,590 (14,646)	6,828 (15,174)	0 (0)	-	0 (0)	13,494 (29,988)	40.0	17,364 (38,587)	14,730 (32,735)
116	11.0	125,856 (279,680)	126,204 (278,281)	44	56,290 (125,089)	629 (1,398)	6,828 (15,174)	0 (0)	-	0 (0)	13,494 (29,988)	40.0	17,364 (38,587)	14,730 (32,735)
117	11.0	111,327 (247,394)	72,162 (160,360)	58	40,527 (90,062)	4,892 (10,873)	5,069 (11,265)	34,272 (76,161)	17	20,546 (45,658)	12,359 (27,464)	36.0	0 (0)	0 (0)
120	11.0	99,788 (221,752)	62,283 (138,407)	58	22,406 (49,792)	4,795 (10,657)	4,741 (10,537)	32,709 (72,688)	17	19,043 (42,318)	18,611 (41,358)	55.0	0 (0)	8,713 (19,363)
121	10.2	82,539 (183,421)	42,803 (95,119)	42	19,705 (43,789)	7,088 (15,752)	3,259 (7,243)	32,647 (72,550)	18	17,264 (38,365)	12,729 (28,288)	52.0	1,484 (3,299)	0 (0)
122	11.5	111,780 (248,401)	76,079 (169,066)	58	37,161 (82,580)	4,517 (10,039)	5,703 (12,675)	31,182 (69,295)	13	18,220 (40,491)	15,001 (33,336)	35.0	1,760 (3,913)	0 (0)
113	11.0	338,620 (752,489)	321,689 (714,865)	28	245,329 (545,177)	16,930 (37,624)	20,301 (45,115)	0 (0)	28	0 (0)	8,085 (17,967)	24.0	11,101 (24,669)	0 (0)
112	11.0	93,482 (207,738)	89,610 (199,134)	24	0 (0)	3,871 (8,604)	4,491 (9,981)	0 (0)	-	0 (0)	34,039 (75,644)	100.0	0 (0)	41,184 (91,521)

[a] Includes CaO.

[b] Basis 89 percent CaO.

generated in the primary increases sharply as percent blowdown is decreased from about 20 percent to zero percent. Figs. 10-1 and 10-2 are based on cases 103-112, presented in Section XV. B.

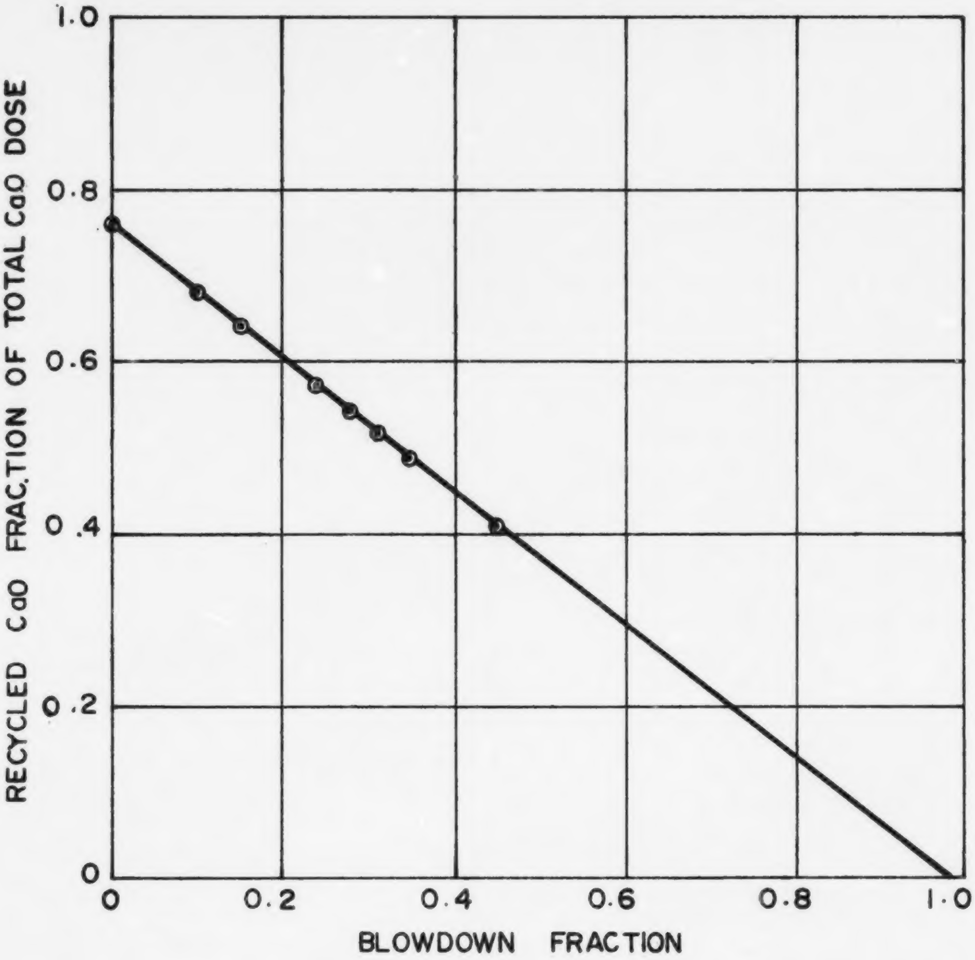

Figure 10-1 Effect of blowdown on recovered CaO

For the Plural Purpose Furnace cases 106, 114, and 116 in which there is a high recovery step for dewatering primary sludge, followed by furnaces for both combined recalcination and incineration of cake solids, there is more sludge production in the primary than for any of the three ATTF System cases (100, 101, and 102) when the makeup lime requirement is comparable. The mass of

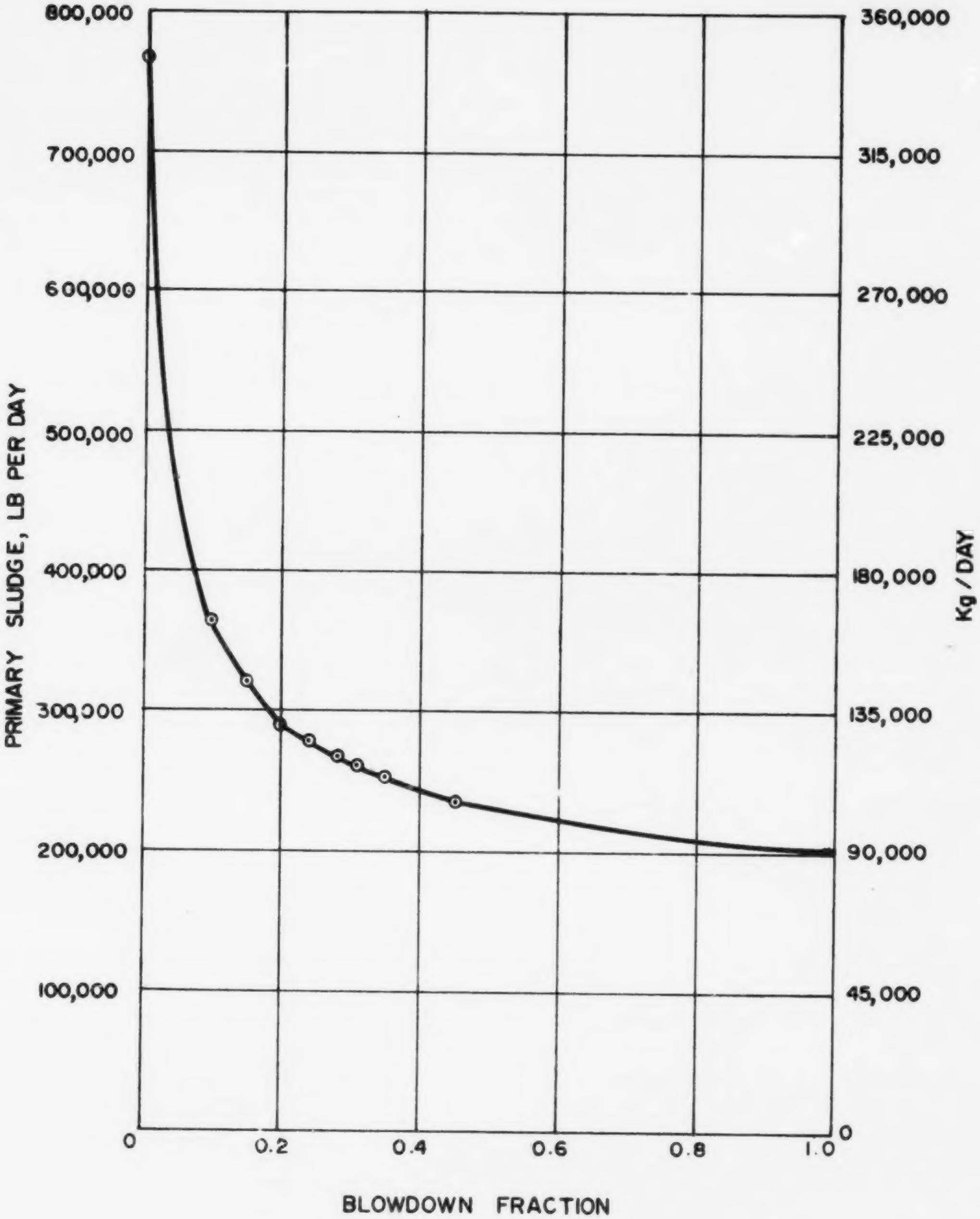

Figure 10-2 Effect of blowdown on primary sludge production for cases 103-112

cake solids to be fed to the Plural Purpose Furnace is greater than the combined amount of first and second stage cake fed to the two furnaces for the ATTF System cases. Further, considering the dryness of the cakes produced, there is more water to be eliminated for the Plural Purpose Furnace cases than the ATTF System cases (Table 7-11).

A basis for judging the effectiveness of wet classification is presented by the computer output listed in Section XV. B. For case 117, the solids that would be produced on a single pass through the primary are 82,527 kg/day (183,395 lb/day). Recycle streams increase primary sludge production to 111,327 kg/day (247,394 lb/day). Thus, 28,799 kg (63,998 lb) of unwanted solids are returned to the primary sedimentation tank amounting to 26 percent of the solids appearing in the underflow. Insertion of dry classification improves the picture considerably (Case 100, Section XV. B). Single pass precipitation for this case is 82,579 kg/day (183,509 lb/day) with recycle streams increasing primary sludge production to 100,940 kg/day (224,312 lb/day). In this case unwanted solids appearing in the primary underflow is 18,361 kg/ day (40,803 lb/day), amounting to 18 percent of the underflow solids. The improvement over case 117 is primarily due to increased silica blowdown attributable to the dry classifier.

The beneficial effect of the dry classification step is portrayed in Table 10-10. Case 100 is an ATTF System case with dry classification whereas, in case 117, the dry classification step has been omitted. As can be deduced from the table, silica builds up to quite high levels (31 percent as SiO_2) in the recalcined product without dry classification; when dry classification is employed the silica is reduced to only 10 percent (as SiO_2) of the recalcined product. Silica in the recalcined product can also be reduced by blowing down directly from the furnace product, instead of by dry classification (case 120, Table 10-10). By using 28 percent blowdown, the silica content can be reduced to 13 percent. However, this is accomplished at the expense of lime consumption. The percentage recycled lime decreases from 62 to 45 percent.

Two other cases were included in Table 10-10, employing pH values of 10.2 and 11.5 in the primary. In Case 121, (pH 10.2) because of increased difficulty of classifying and dewatering the sludge, the percentage of makeup lime is significantly higher than for a similar processing sequence at pH 11.0 (Case 100). At pH 11.5 in the primary (case 122), sludge wet classification and dewatering are slightly improved over the pH 11.0 operation, and the percent of makeup lime required is slightly lower than for the similar operation at pH 11.0 (case 100). The actual mass of makeup lime at pH 11.5 is greater than that required for pH 11.0 operation because of the higher total lime dose needed to reach pH 11.5.

Comparisons between operation at pH 10.2, 11.0 and 11.5 are interesting (Cases 121, 100 and 122 respectively in Table 10-10). Twenty-two percent more solids are generated in the primary at pH 11 than 10.2, while 35 percent more are generated at pH 11.5 than 10.2. The effect of increased sludge production is primarily felt in the recalcination furnace; increased doses of lime increase the quantity of calcium carbonate to be recalcined. It is noticeable that the second stage cake to be incinerated stays fairly constant, despite changes in pH levels between cases.

Table 10-10. CALCULATED SOLIDS BALANCES FOR CASES 100, 117, 120, 121 and 122

Parameter	Solids processing case no.				
	100^a	117^b	120^b	121^a	122^a
pH	11.0	11.0	11.0	10.2	11.5
$Ca(OH)_2$ dose, mg/l	400	400	400	289	500
$FeCl_3$, mg/l	14	14	14	24	0
Recycled lime, percent	62	64	45	48	65
Recalcined product blowdown, percent	0	0	28	0	0
Ash classification	Yes	No	No	Yes	Yes
Primary sludge, kg/day (lb/day)					
Organics	26,222 (58,272)	26,222 (58,272)	26,222 (58,272)	27,923 (62,052)	25,225 (56,057)
$CaCO_3$	53,087 (117,972)	53,124 (118,054)	52,490 (116,646)	33,948 (75,441)	65,996 (146,659)
SiO_2	4,523 (10,053)	14,418 (32,042)	4,562 (10,139)	4,938 (10,975)	4,738 (10,531)
$Ca_3(PO_4)_2$	7,651 (17,003)	7,742 (17,206)	7,184 (15,965)	7,971 (17,714)	7,693 (17,096)
Other^c	9,455 (21,012)	9,819 (21,821)	9,337 (20,750)	7,757 (17,239)	8,126 (18,058)
Total	100,938 (224,312)	111,325 (247,394)	99,795 (221,752)	82,537 (183,421)	111,778 (248,401)
First stage cake, kg/day (lb/day)					
Organics	10,489 (23,309)	10,489 (23,309)	10,489 (23,309)	9,773 (21,718)	10,342 (22,983)
$CaCO_3$	43,797 (97,327)	43,827 (97,394)	43,304 (96,233)	24,443 (54,318)	56,757 (126,127)
SiO_2	4,071 (9,047)	12,976 (28,837)	4,106 (9,125)	4,445 (9,878)	4,312 (9,583)
$Ca_3(PO_4)_2$	1,530 (3,401)	1,548 (3,441)	1,436 (3,193)	2,072 (4,606)	1,769 (3,932)
Other^c	3,089 (6,866)	3,320 (7,379)	2,946 (6,547)	2,069 (4,599)	2,898 (6,440)
Total	62,976 (139,950)	72,160 (160,360)	62,281 (138,407)	42,802 (95,119)	76,078 (169,066)
Recycled solids, kg/day (lb/day)					
CaO	21,257 (47,239)	21,684 (48,187)	15,426 (34,281)	11,863 (26,364)	27,547 (61,217)
$CaCO_3$	2,003 (4,453)	2,038 (4,529)	1,449 (3,222)	1,118 (2,485)	2,596 (5,771)
SiO_2	3,036 (6,747)	12,717 (28,261)	2,897 (6,439)	3,315 (7,367)	3,216 (7,147)
$Ca_3(PO_4)_2$	1,376 (3,059)	1,455 (3,235)	972 (2,161)	1,864 (4,143)	1,591 (3,537)
Other^c	2,288 (5,085)	2,632 (5,851)	1,660 (3,689)	1,543 (3,430)	2,208 (4,908)
Total	29,960 (66,583)	40,526 (90,062)	22,404 (49,792)	19,703 (43,789)	37,158 (82,580)
Second stage cake, kg/day (lb/day)					
Organics	12,271 (27,271)	12,271 (27,271)	12,271 (27,271)	14,157 (31,461)	11,608 (25,797)
$CaCO_3$	9,197 (20,439)	9,203 (20,453)	9,094 (20,209)	7,889 (17,532)	9,147 (20,327)
SiO_2	438 (975)	1,398 (3,108)	442 (983)	400 (889)	413 (919)
$Ca_3(PO_4)_2$	5,508 (12,242)	5,575 (12,389)	5,172 (11,495)	5,485 (12,191)	5,331 (11,847)
Other^c	5,709 (12,687)	5,823 (12,941)	5,728 (12,730)	4,715 (10,478)	4,681 (10,404)
Total	33,123 (73,614)	34,270 (76,161)	32,707 (72,688)	32,646 (72,550)	31,180 (69,295)

[a] Dry classifier in operation.

[b] No dry classifier in operation.

[c] Includes MgO, $Mg(OH)_2$, Fe_2O_3, $Fe(OH)_3$, or acid insoluble inerts.

REFERENCES - SECTION X

1. Brown and Caldwell, Consulting Engineers. Lime Sludge Recycling Study. Prepared for the Central Contra Costa Sanitary District, Walnut Creek, California, June 1974.

2. Parker, D.S., K.E. Train and F.J. Zadick. Sludge Processing for Combined Physical-Chemical-Biological Sludges. U.S. Environmental Protection Agency, Washington, D.C. Report Number EPA-R2-73-250, July 1973. 141 p.

SECTION XI

ULTIMATE DISPOSAL OF ASH

Although incineration of wastewater sludges greatly reduces the volume of waste material, it produces an end product, ash, for which a final place must be found before the solids disposal problem can be considered solved.

ASH CHARACTERISTICS

The term "ash" is somewhat loosely applied to various waste products of incineration and related processes. Apart from the most common use of the name (the solid product of combustion discharged at the bottom of multiple hearth furnaces), dust particles, carried with the off-gases and captured in dry cyclones or removed in a wet scrubber, are sometimes referred to as ash. Finally, the rejects from the dry classification process described in Section VIII, can also be considered as ash, although they contain reactive lime. Each of these ash-like products is handled in a different way but all would eventually converge in a common waste stream to be carried to the point of ultimate disposal.

Gerlich and Rockwell[1] have characterized the physical properties of wastewater sludge ash discharged from a MHF. The data are shown in Table 11-1. The physical and chemical properties of the ash are likely to vary from plant to plant. These differences are due to sludge characteristics, use of chemical conditioners, type of incinerator and combustion temperature. This variation is illustrated in Table 11-2, which shows particle size distribution of ash from three wastewater treatment plants.[2] Gerlich and Rockwell[1] have also reported the results of particle size analyses of sludge ash. These results are shown in Fig. 11-1.

As was mentioned before, combustion ash from a FBR is removed in a wet scrubber. Ash is then separated from the scrubbing water in a hydrocyclone. A particle size analysis of the dried cyclone underflow is given in Table 11-3.[3]

USES OF SLUDGE ASH

Since in wastewater treatment plants practicing sludge incineration there is a continuous supply of the waste product of combustion, attempts have been made from time to time to find a use for it. So far these efforts have been mostly directed towards using ash as a sludge conditioner prior to mechanical dewatering,[1,2] although ash from the organic sludge furnace was experimentally used at South Tahoe to condition flotation thickened mixtures of primary, waste activated and lime sludges prior to incineration.[4] Sludge ash has also been tried as raw material for the phosphate industry[5] and as a construction material.[6]

Table 11-1. PHYSICAL PROPERTIES OF SLUDGE ASH

Specific gravity	2.63-2.78
Bulk density, kg/cu m (lb/cu ft)	800 (50)
Color	Yellow
Mean particle size, mm	29
Range of particle size, mm	22-40

Table 11-2. CLASSIFICATION OF ASH PARTICLES BY "BAHCO" MICRO PARTICLE SIZE ANALYZER

	Percent of given size		
Effective particle size (10^{-3} mm)	Kansas City	Lake Tahoe	Millcreek
0.00 - 0.92	1.49	1.38	2.22
0.92 - 1.60	2.95	2.71	3.70
1.60 - 2.97	5.70	7.53	7.81
2.97 - 7.71	9.05	9.83	21.86
7.71 - 12.19	14.56	10.95	26.52
12.19 - 20.75	22.41	16.20	22.46
20.75 - 24.72	9.21	10.13	6.83
24.72 - 27.30	8.83	4.28	8.60
>28.38	25.80	36.99	∽ 0
<420.			

Table 11-3. PARTICLE SIZE OF "FBR" ASH

Mesh	Microns	Retained %
48	295	2.07
65	208	9.7
100	147	37.0
150	104	43.6
200	74	46.6
325	43	61.8
-325	-43	38.2

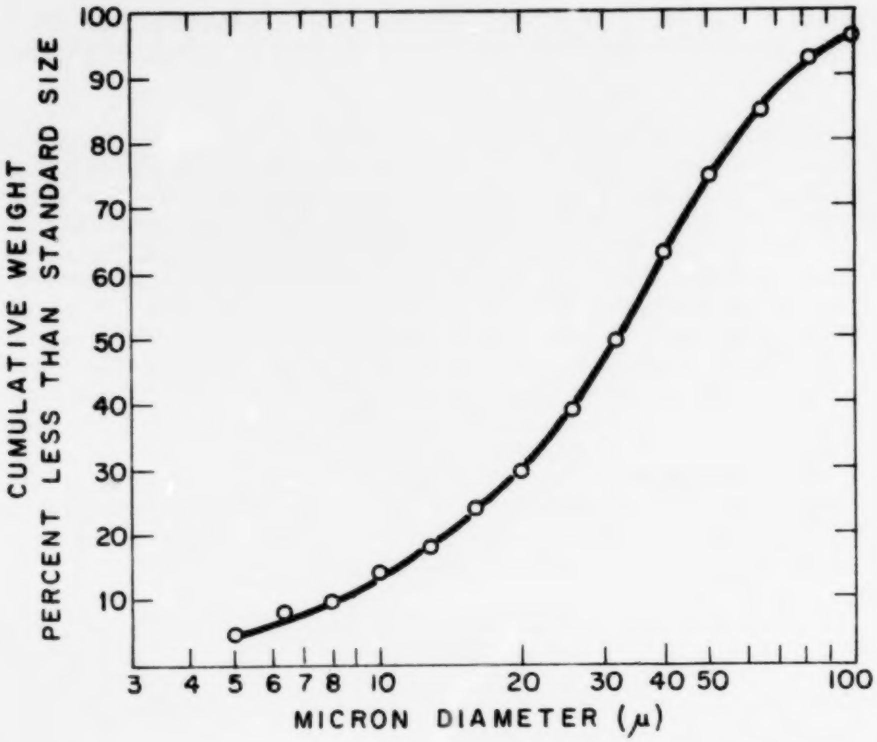

Figure 11-1 Particle size analysis of wastewater sludge ash

Although ash conditioning of wastewater sludges has experienced limited success, the results so far are inconclusive and even conflicting.[1,2] Moreover, this application cannot be considered a method of disposal. The portion of ash added to the sludge is recycled through the dewatering-incineration process while the remaining still has to be disposed of. Also worth noting is the fact that ash acts as an inert filler, thereby lowering the heat content of the sludge cake. This will tend to offset some of the benefits of improved solids dewatering on the cost of sludge incineration.

Obferkuch, et al.[5] prepared an economic analysis of the commercial uses of ash and sludges generated in wastewater treatment plants using lime treatment. In the evaluation of sludge (or ash) for agricultural uses, it was concluded that the product had no economic value in comparison to commercial products (aglime, agrock, and fertilizers), but that it could be given away to farmers. In fact, uses of sludge for agricultural purposes is a common practice in the U.S. and abroad and is, in many cases, an economically feasible method of sludge disposal.

In their evaluation of sludge (or ash) as a product for the phosphate industry, Obferkuch, et al. concluded that the cost of processing the sludge far exceeded the value of the product.

Since the physical and chemical composition of sludge ash is not greatly different than the composition of coal fly ash, Gray and Penessis[6] conducted a study to determine if the former could be used as a construction material. Fly ash has long been successfully used in road subbases, lightweight back-fills and load-bearing fills. Other uses of fly ash include building block material, concrete additive and soil stabilizer. Physical, chemical and engineering properties determined by Gray and Penessis included "grain size distribution, chemical and mineralogic composition, specific gravity, leachate composition, compaction-strength characteristics, frost heave behavior, and response to Portland cement stabilization". Ash samples were obtained from eight wastewater treatment plants. The tests conducted on compacted ash samples showed the suitability of sludge ash as a load-bearing fill, however, ash would have to be stabilized with Portland cement before use in subbases and structural fills. Cement addition requirements ranged from 3 to 7 percent.[6] Significantly, it was concluded that ash from treatment plants using lime for flocculation and sludge conditioning, would have improved strength and durability after wetting and compaction.

Although the potential use of sludge ash appears encouraging, actual use of this product has been limited. Local market conditions and acceptability of ash as a suitable construction and building material are two of the factors more likely to influence its useful application. In the great majority of installations, sludge ash remains a waste product to be disposed of.

ASH HANDLING PRIOR TO DISPOSAL

Ash produced during sludge incineration can be handled in dry or in wet form. Dry ash is discharged from a MHF, from dry cyclones and as rejects from the air classification process (see Section VIII). Wet ash is discharged from wet scrubbers.

Dry Ash Handling

Ash from the MHF, often after grinding and cooling, can be handled in pneumatic or mechanical conveyors. The same devices can be used to convey ash collected in dry cyclones and rejected by air classifiers. The conveyors normally transport the waste product to storage bins, from which it is loaded into trucks and carried to the disposal site. To avoid dusting, the dry ash is normally wetted before being loaded. The screw conveyor transferring the product from storage to truck is often used for the wetting operation, since spray nozzles can be easily installed on the conveyor.

Wet Ash Handling

The handling of wet ash usually follows an elaborate path. In the fluidized bed calciner shown in Fig. 8-6, the underflow of the ash thickener, which contains most of the inert product, is pumped to a vacuum filter for dewatering. The ash cake is then ready for final disposal. In the FBR used for sludge incineration, ash removed in the wet scrubber is separated from the scrubbing water in a hydrocyclone. The cyclone underflow is then dewatered in a rake type classifier from which it is discharged to a storage hopper or to a truck parked underneath.

Dry ash discharged at the bottom of a MHF can also be handled in wet form. The hot product discharges into a quench tank where cooling water is added. The ash slurry thus formed is subsequently pumped to the disposal site. Abrasion-resistant pumps, of the type used to handle grit slurries, are recommended for this application.

When wet scrubbing is the last step in the dust collection train, the amount of ash removed in the scrubber can be expected to be small and the scrubbing water can be discharged to the drainage system and returned to the influent end of the plant. This is often the case in a MHF installation (see Fig. 8-11).

FINAL DISPOSAL SITES

When a beneficial use is not found, sludge ash is normally disposed of in landfills or in lagoons. The former is generally associated with dry transport while the latter is used when ash is handled as a slurry. Dry ash deposited in a landfill should be covered before the water added during loading evaporates and the dried ash causes a serious dusting problem. Ash lagoons are similar to conventional sludge lagoons, although the potential odor problem associated with the latter does not exist in ash lagoons. As shown in Table 11-1, sludge ash has a high specific gravity and will settle rapidly in the lagoon. As long as a layer of water is kept over the settled ash, the possibility of drying and dusting is eliminated.

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SECTION XII

DEVELOPMENT OF COST ESTIMATES

GENERAL CONSIDERATIONS

It has been customary practice to present cost data in the form of cost curves relating a given design parameter, such as flow, organic loading, etc., to a certain type of cost, such as construction, capital, annual, etc. The curves are generally adjusted to a common base year through a cost index. Among these, the Engineering News Record (ENR) Construction Cost Index is the most widely used. Although useful for preliminary cost estimates to compare engineering alternatives, there are practical limitations to the use of cost curves. The curves normally reflect average conditions and therefore do not reflect the influence of several important factors. These factors include soil conditions, architectural and landscaping treatment, allowances for future expansion, local labor conditions, degree of automation, process sophistication, etc. With regards to new treatment processes, another important drawback of cost curves is the limited availability of actual construction and operation and maintenance cost data from which the curves may be constructed, since many of these plants are still in the planning and design stages.

In view of the factors considered above, a Case Example format has been determined to be a more suitable approach for this report. Since the water reclamation plant for the Central Contra Costa Sanitary District (CCCSD), California, was bid in June 1973, actual construction costs for many of the main processes described in the preceeding sections are now available and can be readily adjusted to reflect present economic conditions. Construction costs are broken down in this section by unit operations, i.e., chemical addition, flocculation and sedimentation; centrifugation; etc. To present variations in the basic flow sheet, alternate units are substituted for the original ones; for example, centrifuges have been replaced by vacuum filters and filter presses.

Detailed engineering cost estimates were also available for another advanced treatment plant, the Lower Molonglo Water Quality Control Centre in Australia. Estimates from this facility have been used to illustrate the cost difference between solids-contact lime reactors and rectangular flocculation and sedimentation tanks.

Operating costs are based on chemical use, installed horsepower, and fuel consumption where applicable. Fuel use has been based on materials and heat balances similar to those developed in Section VIII and presented in an engineering report.[1] With the exception of calcination and incineration processes, where the continuous presence of an operator is normally required by codes, it is difficult to assign a cost value to operator attendance since this is a direct function of the degree of automation provided, which varies widely from plant to plant. As an example, the CCCSD water reclamation plant is entirely controlled by a computer-based system and most processes are continuously monitored by the computer.[2] The presence of an operator for control purposes is therefore not required. This is certainly not the case in smaller or less sophisticated facilities where conventional analog instruments are used or manually controlled units have been provided.

Wherever possible, maintenance costs have been based on the equipment manufacturer's recommendations for preventive maintenance frequency and procedures. It should be pointed out that, with the possible exception of the largest treatment plants, equipment maintenance is performed by the plant operators; consequently, for smaller plants a portion of the manpower requirements for preventive maintenance is included under operation attendance.

THE LOWER MOLONGLO WATER QUALITY CONTROL CENTRE

The Lower Molonglo Water Quality Control Centre is an advanced treatment facility for the Australian Capital territory. Initial dry weather flow capacity of the plant is 109,000 cu m/day (28.8 mgd), practically equal to the capacity of the CCCSD water reclamation plant. The treatment processes include lime coagulation for phosphorous and solids removal; nitrogen removal by a modified nitrification-denitrification system; dual media filtration for removal of virus and residual suspended solids; effluent disinfection; wet classification and solids dewatering by centrifugation; lime reclamation; and solids disposal by incineration.

Originally, design of the plant included solids-contact clarifiers and ammonia stripping towers for nitrogen removal.[3] Subsequently, limitations of the ammonia stripping process led to its replacement by a modified nitrification-denitrification process.[4] Also, the dry classification of recalcined lime initially considered, was replaced by a combination of wet and dry classification, based on the experimental worked conduct at the CCCSD's ATTF (see Sections VII and VIII). The solids-contact lime reactors were substituted with rectangular sedimentation tanks. This change was also based on results obtained at the ATTF.[5] Design parameters for both types of flocculation-sedimentation tanks are given in Table 12-1.

The two design reports on the Lower Molonglo WQCC included detailed engineer's estimates of construction costs of the proposed facilities. Costs were based on bidding conditions prevailing in Australia in June 1970. Table 12-2 shows costs in Australian dollars for both types of flocculation-settling basins. Since the purpose is to compare these two alternatives, the figures given in Table 12-2 have not been converted to American dollars nor adjusted to reflect present construction costs. However, it can be seen that rectangular tanks are considerably less costly than solids-contact clarifiers. Although the original Lower Molonglo WQCC design contemplated solids dewatering by vacuum filtration following gravity thickening; and therefore, the proposed processes did not include grit removal; grit removal chambers ahead of the primaries have been added to the cost of the solids-contact clarifiers alternative in Table 12-2, to put the comparison on an equal treatment basis.

Table 12-1. DESIGN DATA FOR FLOCCULATION - SEDIMENTATION BASINS AT THE LOWER MOLONGLO WQCC

Parameter	Solids-contact clarifier	Rectangular flocculation[a] - sedimentation tanks
Lime dosage, mg/l as CaO	250	250
Solids - contact clarifiers		
Number	3	-
Diameter, m (ft)	42.7 (140)	-
Depth, m (ft)	6.1 (20)	-
Effective surface area each, sq m (sq ft)	1,208 (13,000)	-
Overflow rate at ADWF,[b] cu m/day sq m (gpd/sq ft)	24.9 (610)	-
Detention time in flocculation zone at ADWF,[b] min	20	-
Detention time at ADWF,[b] hr	5.8	-
Hydraulic capacity each, 1,000 cu m/day (mgd)	125 (33)	-
Preaeration-grit removal tanks		
Number	-	2
Width, m (ft)	-	9.1 (30)
Length, m (ft)	-	24.1 (79)
Average depth, m (ft)	-	4.0 (13)
Detention time at ADWF,[b] min	-	24
Primary sedimentation tanks		
Number	-	4
Width, m (ft)	-	11.9 (39)
Length, m (ft)	-	67.1 (220)
Average depth, m (ft)	-	2.9 (9.5)
Overflow rate at ADWF,[b] cu m/day sq m (gpd/sq ft)	-	28.8 (705)
Detention time at ADWF,[b] hr	-	2.1
Hydraulic capacity each, 1,000 cu m/day (mgd)	-	151 (40)

[a] Preaeration and grit removal tanks used for flocculation.
[b] Average dry weather flow.

Table 12-2. COST COMPARISON BETWEEN SOLIDS-CONTACT CLARIFIERS AND RECTANGULAR FLOCCULATION-SEDIMENTATION TANKS

Cost item	Solids-contact clarifiers	Rectangular tanks
Solids separation	1,035,000	753,000
Preaeration - grit removal	602,000	602,000
Total, A.$	1,637,000	1,355,000

THE CCCSD WATER RECLAMATION PLANT

The water reclamation plant is a 114,000 cu m/day (30 mgd) facility scheduled for completion in 1976. Once in operation, the plant will produce water for industries located along the southern shore of Suisun Bay, in the Sacramento River estuary. In 1972 the CCCSD completed contract negotiations with the Contra Costa County Water District (CCCWD) for the purchase of an estimated 72,000 cu m/day (19 mgd) increasing by 1980 to an average of 91,000 cu m/day (24 mgd) with a peak daily use of 121,000 cu m/day (32 mgd). Industries will use about 75 percent of the reclaimed water for cooling and the remainder for process purposes. Reclaimed water that is produced in excess of industry's needs will be discharged directly to Suisun Bay. A flow diagram of the CCCSD water reclamation plant is shown in Fig. 12-1. As stated in Section VI, lime is added ahead of the preaeration and grit removal tanks. A brief description of the plant units associated with lime treatment, recovery and reuse is given below.

Liquid Processing

After bar screening and influent pumping, combined preaeration and grit removal will be obtained in two reinforced concrete tanks designed to provide a detention time of 20 minutes at average dry weather flow. Air at the rate of 0.08 to 0.16 cu m/min (3 to 6 cfm) per foot of tank length will be introduced along the side of each tank through header pipes fitted with air diffusion units. Grit will be removed as a result of the currents set up by the rising column of air and deposited in hoppers under the air piping. Material in the hoppers will be pumped directly to cyclonic separators located in the solids conditioning building. After dewatering, grit will be conveyed to the sludge incineration furnace. Lime will be added to the wastewater flow in the distribution channel feeding the preaeration and grit removal tanks. Lime coagulation of the wastewater will be performed in the air-stirred preaeration tanks.

Primary sedimentation will take place in four rectangular reinforced concrete tanks. Each tank is designed for a detention period of 2.2 hours and an overflow rate of 31.8 cu m/day/sq m (780 gpd/sq ft) at average dry weather flow conditions. Each sedimentation tank will be equipped with two longitudinal sludge collection mechanisms and a cross collector. After collection at the influent end of the tanks, the lime sludge will be removed by positive displacement pumps and pumped first to the sludge thickening tanks. From there, it will be discharged at a constant rate to the solids dewatering and incineration processes. Scum collected on the water surfaces in the sedimentation tanks will be moved to the inlet ends by water jets and removed from the tanks by skimming mechanisms which will drop the accumulated material to a receiving sump. From here, primary scum will be pumped to a scum concentrator at the solids conditioning building. Thickened scum will then be incinerated.

Solids Processing

The solids processing systems consist of processes for classification and dewatering of the primary sedimentation tank underflow; scum and grit dewatering; recalcining of the calcium carbonate-rich solids discharged from the centrifuge

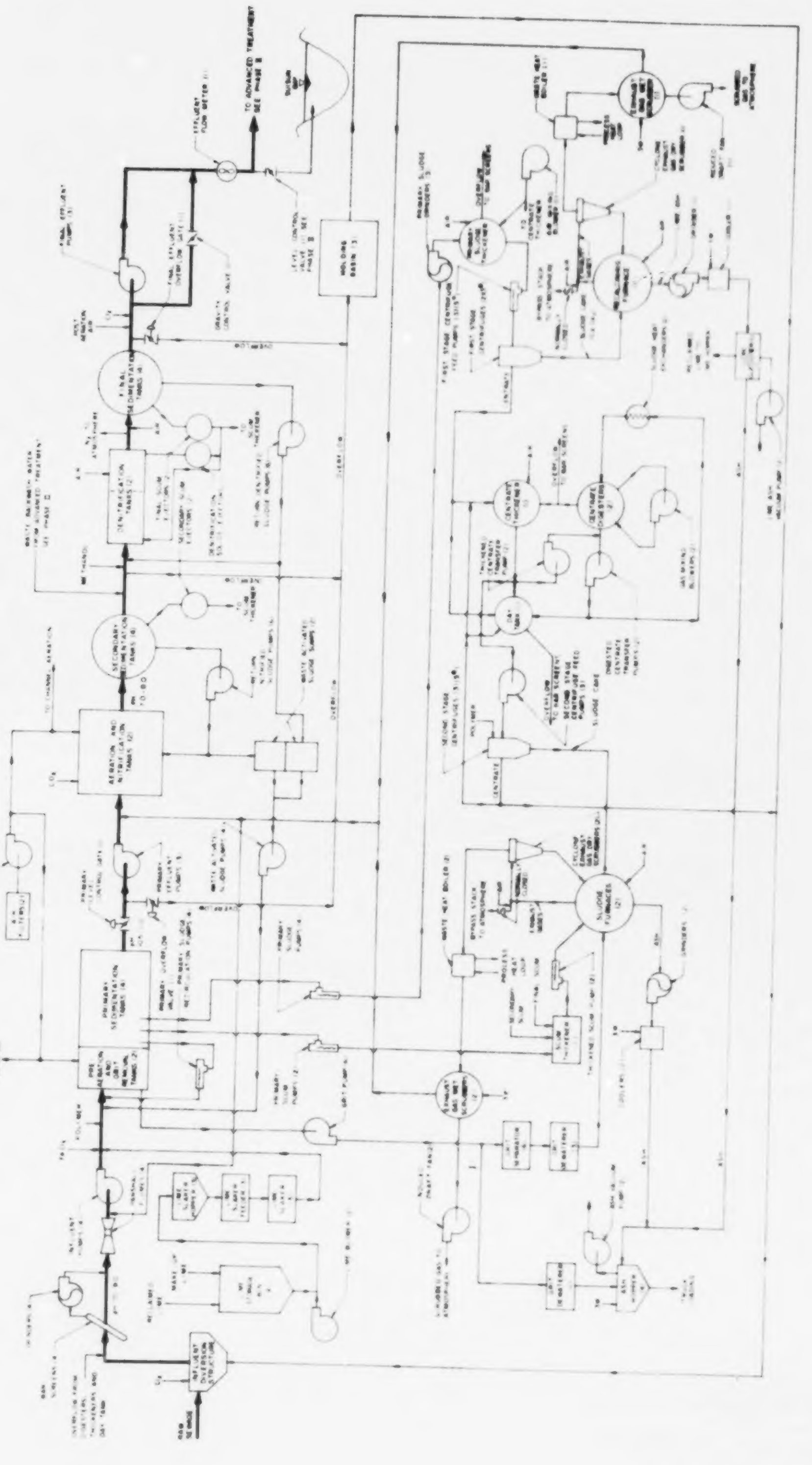
RAW SEWAGE
INFLUENT DIVERSION STRUCTURE
PRIMARY SEDIMENTATION TANKS (4)
AERATION AND NITRIFICATION TANKS (2)
SECONDARY SEDIMENTATION TANKS (4)
DENITRIFICATION TANKS (2)
FINAL SEDIMENTATION TANKS (4)
TO ADVANCED TREATMENT SEE PHASE II
EFFLUENT FLOW METER (1)
HOLDING BASIN (1)
SLUDGE FURNACES (2)
OVERFLOW

Figure 12-1. Flow diagram of the CCCSD water reclamation plant.

classification stage; and incineration of the solids discharged from the dewatering stage, together with the dewatered scum and grit. Two of the existing sludge digestion tanks will be used as storage and thickening tanks for the sludge underflow from the primary sedimentation tanks. The modified tanks consist of circular reinforced concrete tanks 18.9 m (62 ft) in diameter and side water depths of 7.2 m (23.5 ft) and 9.9 m (32.5 ft).

The solid-bowl centrifuges will operate in series. The first stage centrifuges will classify or separate the phosphorus and organic solids from the calcium solids, and the second stage centrifuges will dewater the centrate discharged from the first stage centrifuge. The calcium solids discharged in the cake from the first stage centrifuges will be recalcined in multiple hearth furnaces, and the undesirable chemical precipitates and organic solids will be discharged in the centrate. The second stage dewatering centrifuges will produce a centrate of high clarity, and the cake will be discharged to the sludge, scum, and grit incinerating furnace.

The multiple-hearth furnaces will be equipped with sufficient drying, combustion and cooling hearths to provide odor-free operation and complete combustion of all organic material. The temperature in the combustion zone will be automatically controlled to ensure efficient combustion, and each incinerator will be equipped with a full complement of safety controls. The furnaces are designed for recalcining of lime sludge as well as for combustion of organic material. All gases of combustion will be afterburned at 760 C (1400 F) and scrubbed in dry scrubbers. Waste heat boilers will be used to recover heat in the form of steam. The exit gas from the boilers will be cooled in wet scrubbers and, when necessary, reheated prior to release to the atmosphere to prevent the formation of a vapor plume on cold days.

Recalcined lime from the furnaces will be conveyed pneumatically to lime storage bins located in the chemical storage area. Sufficient storage volume will be provided for a full week's supply of lime, and makeup lime may be added to the storage bins through a pneumatic delivery system from bulk delivery trucks or rail cars. Lime will also be conveyed pneumatically from storage to the lime feeders and slakers. The slakers and the automatically controlled gravimetric-type feeders will be located just above the distribution channel feeding the preaeration and grit removal tanks.

Table 12-3 shows the design data for the processes described in the preceeding paragraphs. Some differences will be noted in the solids loads as indicated in Table 12-3 and the current solids balance for the system (Case 100, Section XV). These reflect the estimates prevailing at the time of design vs. the post design estimates prevailing currently. Design values are shown in Table 12-3, since they were the basis of design.

COST ESTIMATES FOR THE CCCSD WATER RECLAMATION PLANT

Detailed cost estimates will be presented for the following processes:

1. Lime addition, flocculation and sedimentation.

Table 12-3. DESIGN DATA FOR CCCSD WATER RECLAMATION PLANT

Design Loadings - Stage 5A		
Population served, thousands	310	
Flow contribution, l pcd (gpcd) (industrial flow not included)	303	(80)
Flow		
Average dry weather cu m/day (mgd)	113,550	(30)
Maximum dry weather cu m/day (mgd)	181,680	(48)
Peak wet weather cu m/day (mgd)	529,900	(140)
Loadings		
BOD, 1,000 kg/day (1,000 lb/day)	24.5	(54)
BOD, including recycle 1,000 kg/day (1,000 lb/day)	27.2	(60)
Suspended solids, 1,000 kg/day (1,000 lb/day)	27.2	(60)
Suspended solids, including recyicle, 1,000 kg/day (1,000 lb/day)	32.7	(72)
Total nitrogen as N, mg/l	30	
Total phosphorus as P, mg/l	11	
Preaeration, Flocculation, Grit Removal		
Tanks		
Number, one existing	2	
Width, m (ft)	9.1	(30)
Length, m (ft)	18.8	(61.5)
Average water depth, m (ft)	4.6	(15)
Design capacity, cu m/day (mgd)	113,550	(30)
Detention time, ADWF, hr	0.33	
Max hydraulic capacity, cu m/day (mgd)	283,875	(75)
Air supplied, cu m/m (cu ft/gal)	0.74	(0.10)
Grit pumps		
Number	6	
Capacity, each unit, l/sec (gpm)	12.6	(200)
Primary Chemical Feed Equipment		
Lime slaker hopper		
Number	3	
Capacity, each unit, cu m (cu ft)	2.1	(75)
Lime feeder		
Number	3	
Type	gravimetric	
Capacity, each unit, kg (lb) CaO per hour	3,630	(8,000)
Lime slaker		
Number	3	
Type	paste	
Capacity, each unit, kg (lb) CaO per hour	3,630	(8,000)
Primary Sedimentation		
Tanks		
Number, two existing	4	
Width, (ft)	11.6	(38)
Length, (ft)	77.4	(254)
Average water depth, (ft)	2.9	(9.5)
Detention time, ADWF, hr	2.2	
Overflow rate, ADWF, cu m/day/sq m (gpd/sq ft)	31.8	(780)
Mean forward velocity, m/min (ft/min)	0.58	(1.9)
Design capacity, each tank, cu m/day (mgd)	37,850	(10)
Max hydraulic capacity, each tank, cu m/day (mgd)	141,938	(37.5)
Effluent collection pipes		
Number per tank	4	
Diameter, cm (inch)	50.8	(20)
Primary sludge pumps		
Number	4	
Capacity, each unit, 1/sec (gpm)	12.6	(200)
Primary sludge recirculation pumps		
Number	2	
Capacity, each unit, l/sec (gpm)	3.8	(60)
Primary scum pumps		
Number	2	
Capacity, each unit, l/sec (gpm)	3.8	(60)

(continued)

Table 12-3. DESIGN DATA FOR THE CCCSD WATER RECLAMATION PLANT (CONTINUED)

Primary Treatment Performance		
BOD removal		
Percent	70	
1,000 kg/day (1,000 lb/day)	19.1	(42)
Suspended solids removal		
Percent	70	
1,000 kg/day (1,000 lb/day)	22.7	(50)
Primary Effluent		
BOD, 1,000 kg/day (1,000 lb/day)	8.2	(18)
Suspended solids, 1,000 kg/day (1,000 lb/day)	10	(22)
Sludge Thickening		
Primary sludge thickener (existing digester)		
Tanks		
Number	1	
Diameter, m (ft)	18.9	(62)
Side water depth, m (ft)	5.84	(19.17)
Surface area, sq m (sq ft)	280	(3,020)
Volume, each tank, 1,000 cu m(1,000 cu ft)	1.7	(62)
Detention time, hr	23	
Sludge to thickener, 1,000 kg/day (1,000 lb/day)	110.3	(243)
Surface loading, kg/day/sq m (lb/day/sq ft)	390	(80)
Solids recovery, percent	90	
Average sludge solids conc, percent	6	
Average thickened sludge solids conc, percent	8	
First stage centrifuge feed pumps		
Number	3	
Capacity, each unit, l/sec (gpm)	20.8	(330)
Air mixing blower		
Number	2	
Capacity, each unit, at discharge pressure, cu m/min (cfm)	35	(1,250)
Discharge pressure, kg/sq cm (psig)	1.3	(18)
Centrate thickener, (existing digester)		
Tanks		
Number	1	
Diameter, m (ft)	18.9	(62)
Side water depth, m (ft)	10.11	(33.17)
Surface area, sq m (sq ft)	280	(3,020)
Volume, 1,000 cu m (1,000 cu ft)	2.7	(95)
Detention time, hr	22	
Sludge to thickener, 1,000 kg/day (1,000 lb/day)	58	(128)
Surface loading, kg/day/sq m (lb/day/sq ft) DS	205	(42)
Solids recovery, percent	90	
Average centrate solids conc, percent	1.5	
Average thickened centrate solids conc, percent	3	
Second stage centrifuge feed pumps		
Number	3	
Capacity, each pump, l/sec (gpm)	26.5	(420)
Centrifugation		
First stage centrifuge		
Number	2	
Type	solid bowl	
Max feed rate, l/sec (gpm)	16.1	(255)
Feed solids conc, percent	8	
Max G force, G	3,100	
Cake solids conc, percent	55	
Centrate solids conc, percent	2	
Horsepower	250	
Second stage centrifuge		
Number	2	
Type	solid bowl	
Max feed rate, l/sec (gpm)	16.4	(260)
Feed solids conc, percent	4	
Max polymer dosage, kg/ton (lb/ton) DS	0.9	(2)
Max G force, G	3,100	
Cake solids conc, percent (minimum)	14	
Centrate solids conc, percent	0.5	
Horsepower	250	

(continued)

Table 12-3. DESIGN DATA FOR THE CCCSD WATER RECLAMATION PLANT (CONTINUED)

Furnaces		
Sludge incineration		
Number	1	
Type	MHF	
Outside diameter, m (ft)	6.78	(22.25)
Hearths	11	
Off gas temperature C (F)	760	(1,400)
Ash, kg/hr (lb/hr)	817	(1,800)
Loading, 1,000 kg/day (1,000 lb/day) DS	31.8	(70)
Feed solids conc, percent	12-18	
Volatile solids, percent	43	
Lime recalcination		
Number	1	
Type	MHF	
Outside diameter, (ft)	6.78	(22.25)
Hearths	11	
Off gas temperature C (F)	760	(1,400)
Ash, kg/hr (lb/hr)	1,589	(3,500)
Loadings, 1,000 kg/day (1,000 lb/day) DS	68	(150)
Feed solids conc percent	50-60	
Volatile solids, percent	21	
$CaCO_3$ feed, 1,000 kg/day (1,000 lb/day)	44.5	(98)
Furnace Auxiliary Equipment		
Lump breaker		
Number	2	
Capacity, each unit, kg (lb) per hour	2,270	(5,000)
Ash cooler		
Number	2	
Outlet ash temperature, C (F)	93	(200)
Exhaust gas equipment		
Dry scrubber		
Number	2	
Max entering gas temperature, C (F)	760	(1,400)
Efficiency, percent	70	
Waste heat boiler		
Number	2	
Capacity, each unit, mil kg-cal/hr (mil Btu/hr)	8.8	(35)
Max entering gas temperature, C (F)	760	(1,400)
Exiting gas temperature, C (F)	232	(450)
Wet scrubber		
Number	2	
Max entering gas temperature, C (F)	288	(550)
Exiting gas temperature, C (F)	49	(120)
Scrubber water pumps		
Number	12	
Capacity, each pump, l/sec (gpm)	54.3	(860)
Ash hoppers		
Number	4	
Capacity, each hopper, cu m (cu ft)	35	(1,250)
Sludge, Scum and Grit Reduction		
Loadings		
Scum, kg/day (lb/day) DS	636	(1,400)
Grit, kg/day (lb/day) DS	1,272	(2,800)
Sludge 1,000 kg/day (1,000 lb/day)	31.8	(70)
Volatile solids, percent	43	
Feed solids conc, percent	12-18	
Scum dewatering equipment		
Thickener		
Number	1	
Surface loading kg/day/sq m (lb/day/sq ft) DS	68.3	(14)
Thickened scum pumps		
Number	2	
Capacity, each pump, l/sec (gpm)	0.09	(1.5)
Grit dewatering equipment		
Separator		
Number	4	
Capacity, each unit, l/sec (gpm)	6.3	(100)
Dewaterer		
Number	2	
Capacity, each unit, l/sec (gpm)	7.9	(125)

2. Gravity sludge thickening.
3. Sludge classification and dewatering.
4. Lime recalcination and sludge incineration.
5. Related processes, i.e., heat recovery and pneumatic conveying.

The basic cost will be developed for the type of units included in the CCCSD plant. As previously stated, these units will be replaced for illustration purposes by other units capable of comparable performance. The alternates considered are:

1. Dewatering of first stage centrate by pressure filtration prior to sludge incineration.
2. Primary sludge dewatering by vacuum filtration prior to lime recalcination in Plural Purpose furnaces.

Capital Costs

Capital costs of the units associated with the lime treatment and recovery at the CCCSD's plant are presented in Table 12-4. Construction costs given in the table are representative of bidding conditions in the San Francisco Bay Area during June 1973, representing an ENR Construction Cost Index of 2000. These costs are based on a combination of the engineer's estimate and bidding information submitted by the general contractor. Engineering includes field surveying and soil investigations, design, preparation of plans and specifications, office engineering during construction, resident engineering, inspection, materials testing and construction surveying. Engineering costs depend on factors such as the size and complexity of the work, required construction period, owner facilities, etc. Engineering charges are computed by several methods, or combination of two or more of these methods.[6] In the table a value of 12 percent has been used for illustration purposes. Contingencies cover such factors as removal of unknown structures and alterations and changes during construction. Contingency charges for construction are usually set at 5 to 10 percent of the total construction cost of the project. A contingency allowance of 5 percent has been used in Table 12-4 to arrive at a total capital cost.

In Section VII, a comparison of dewatering techniques was made for a 1.31 cu m/sec (30 mgd) plant. The results of this comparison are shown in Table 7-10. The data presented in Table 7-10 have been used in the evaluation of the impact of alternate dewatering equipment on lime treatment costs as if this equipment had been applied to the CCCSD water reclamation plant. Table 12-5 presents capital cost data for the substitution of vacuum filters for two-stage centrifugal dewatering, converting the CCCSD design from an ATTF processing system (Fig. 7-9) to a Plural Purpose Furnace flow sheet (Fig. 7-8). Another estimate is presented in Table 12-6 which involves the substitution of filter presses for the second stage centrifugal dewatering of the CCCSD design. The two alternatives evaluated produce differing quantities of wet sludge to be incinerated. This has a significant impact on MHF sizing and cost. To account for this effect,

Table 12-4. CAPITAL COST FOR LIME TREATMENT AND RECOVERY AT THE CCCSD WATER RECLAMATION PLANT

Item	Process	Struct. & bldg.[a]	Mechanical equip.[b]	Piping	Elect. & instrumentation[c]	Total cost, dollars[d]
I	Flocculation, grit removal and primary sedimentation. Includes one covered preaeration tank and two sedimentation tanks; distribution and effluent channels; preaeration, sludge collection and scum removal equipment; lime feed building and equipment; equipment gallery; grit, sludge and scum pumps; piping; electrical switchgear; controls and instrumentation.					
	1. Lime feeders and slakers (three units).	81,000	110,000	2,000	17,000	210,000
	2. Flocculation and grit removal tank.	163,000	33,000	66,000	61,000	323,000
	3. Primary sedimentation tanks.	408,000	301,000	31,000	174,000	914,000
	Subtotal					1,447,000
II	Gravity sludge thickening. Includes conversion of two existing digesters to thickeners; sludge thickening equipment; piping; controls and instrumentation.	36,000	93,000	9,000	12,000	150,000
III	Wet classification. Includes two vertical centrifuges; piping; controls and instrumentation.	e	439,000	209,000	85,000	733,000
IV	Sludge dewatering. Includes two vertical centrifuges; polymer feed equipment; piping; controls and instrumentation.	5,000[f]	464,000	217,000	91,000	777,000
V	Lime recalcination. Includes one complete multiple hearth furnace; material conveyors; dry classification equipment; piping; switchgear; controls and instrumentation.	463,000	2,194,000	26,000	396,000	3,079,000
VI	Sludge incineration. Includes one complete multiple hearth furnace; material conveyors; grit and scum handling equipment; piping; switchgear; controls and instrumentation.	467,000	2,291,000	55,000	418,000	3,231,000
VII	Related process.					
	1. Heat recovery equipment. Includes two waste heat recovery boilers and two package steam boilers; boiler feed water system; piping; controls and instrumentation.	e	446,000	213,000	88,000	747,000

Table 12-4. CAPITAL COST FOR LIME TREATMENT AND RECOVERY AT THE CCCSD WATER RECLAMATION PLANT (CONTINUED)

Item	Process	Struct. & bldg.[a]	Mechanical equip.[b]	Piping	Elect. & instrumentation[c]	Total cost, dollars[d]
VII	2. Pneumatic conveying and storage. Includes pneumatic conveying equipment to (a) unload make up lime, (b) transport reclaimed lime from furnace to storage bins, (c) transfer process lime from storage to slaker day hoppers, (d) transport ash to storage; lime storage bins; blowers and auxiliary equipment; screw conveyors; rotary air locks; air filters; piping; controls and instrumentation.	g	g	g	g	593,000
	3. Auxiliary facilities. Includes the percentage allocated to solids processing of administration and maintenance buildings; piping tunnels; outside piping; fuel storage; electrical substations and general site development.	g	g	g	g	3,091,000
Total construction cost						13,848,000
Engineering, 12 percent of construction cost						1,662,000
Contingencies, 5 percent of construction cost						692,000
Total capital cost						16,202,000

[a] When facilities are housed in multipurpose structures and buildings, cost were obtained in proportion to floor space occupied.
[b] Includes installation cost.
[c] Does not include computer cost.
[d] Based on June 1973 prices (ENR Index: 2,000).
[e] Equipment housed in the furnace building.
[f] Cost of housing polymer feed equipment only.
[g] Lump sum.

Table 12-5. CAPITAL COST OF ALTERNATE DEWATERING PROCESS AT THE CCCSD PLANT – VACUUM FILTERS IN A PLURAL PURPOSE FURNACE FLOW SHEET

Item	Process	Struct. & bldg.[a]	Mechancial equip.[b]	Piping	Elect. & instrumentation[c]	Total cost, dollars[d]
-	From total construction cost in Table 12-4, delete items III, IV, V and VI.	-	-	-	-	6,028,000
VIII	Vacuum filters.[e] Includes three belt-type vacuum filters complete with base; vacuum, sludge and filtrate pumps; cake conveyor; chemical conditioning equipment; piping; controls and instrumentation.	212,000	430,000	321,000	74,000	1,037,000
IX	Lime and sludge furnaces.[f] Includes two complete multiple hearth furnaces; material conveyors; dry classification equipment; grit and scum handling equipment; piping; switchgear; controls and instrumentation.	930,000	4,485,000	81,000	814,000	6,310,000
X	Add allowance on items IX for larger furnaces.[g]	-	-	-	-	701,000
Total construction cost						14,076,000
Engineering, 12 percent of construction costs						1,689,000
Contingencies, 5 percent of construction cost						704,000
Total capital cost						16,469,000

[a] When facilities are housed in multipurpose structures and buildings, cost were obtained in proportion to floor space occupied.
[b] Includes installation cost.
[c] Does not include computer cost.
[d] Based on June 1973 prices (ENR index: 2,000).
[e] Vacuum filters to be housed in enlarged furnace building; see Table 7-11 for equipment sizing.
[f] Furnaces operated in Plural Purpose mode (20% blowdown).
[g] Maximum solids load is 39 kg/sq m/hr (8 lb/sq ft/hr) vs. 35.1 kg/sq m/hr (7.2 lb/sq ft/hr) for the CCCSD plant design (See Table 12-10).

Table 12-6. CAPITAL COST OF ALTERNATE DEWATERING PROCESS AT THE CCCSD PLANT - FILTER PRESSES SUBSTITUTED FOR CENTRIFUGAL DEWATERING IN THE SECOND PHASE

Item	Process	Struct. & bldg.[a]	Mechanical equip[b]	Piping	Elect. & instrumentation[c]	Total cost, dollars[d]
-	From total construction cost in Table 12-4, delete Item IV.	-	-	-	-	13,071,000
XI	Filter presses.[e] Includes four 7.4 kg/sq cm (105 psi) filter presses complete with drip flaps, safety curtains, cloths, feed pump, piping, controls and instrumentation.	254,000	880,000	128,000	203,000	1,165,000
XII	Less allowance on Items VI and VI for smaller furnaces.[f]	-	-	-	-	2,103,000
Total construction cost						12,733,000
Engineering, 12 percent of construction						1,528,000
Contingencies, 5 percent of construction cost						637,000
Total capital cost						14,898,000

[a] When facilities are housed in multipurpose structures and buildings, cost were obtained in proportion to flow space occupied.

[b] Includes installation cost.

[c] Does not include computer cost.

[d] Based on June 1973 prices (ENR Index: 2,000).

[e] Filter presses to be housed in enlarged furnace building, see Table 7-11 for equipment sizing.

[f] Maximum solids load is 23.4 kg/sq m/hr (4.8 lb/sq ft/hr) vs. 35.1 kg/sq m/hr (7.2 lb/sq ft/hr) for the CCCSD plant design (See Table 12-10).

the cost of the multiple hearth furnaces in the two alternates were adjusted upwards or downwards proportionate to the wet sludge load on the MHF.

The capital cost of the Plural Purpose Furnace flow sheet is 2 percent more costly than the CCCSD design, while the substitution of filter presses yields costs 14 percent less costly than the CCCSD design.

Operation and Maintenance Costs

Predicted operation and maintenance (O&M) costs of the lime treatment and recovery processes at the CCCSD water reclamation plant are given in Table 12-7. The cost of operating labor shown in the table reflect the computer control features of the CCCSD plant. Labor charges include a proportional share of the cost of administration, supervisory and laboratory staff recommended for the water reclamation plant. In computing operating outlays, the following unit costs were used:

Power: 1.283 ¢/kw-hr
Natural gas: 6.148 ¢/1000,000 Btu (1 Therm)
Lime (92% CaO): $30.55/ton
Ferric Chloride (dry basis) $100/ton as $FeCl_3$
Anionic polymer: $1.25/lb
Labor cost (including fringe benefits) $9.00/man-hr.

The O&M costs for the alternate dewatering processes described in Tables 12-5 and 12-6, are given in Tables 12-8 and 12-9, respectively. Fuel costs in Tables 12-7, 12-8 and 12-9 are based on material balances calculated using the computer program described in Section X. A summary of fuel requirements of the cases studied is given in Table 12-10. Comparing O&M costs, it can be seen that the Plural Purpose flow sheet (Table 12-8) is 7 percent more costly than the CCCSD design, while the filter press alternate is 9 percent less costly than the CCCSD design.

Total Annual Costs

Total annual costs are compared in Table 12-11. The CCCSD design is 3.5 percent less costly than the Plural Purpose flow sheet. Substitution of filter presses for the centrifuges in the second stage dewatering step at the CCCSD design would allow savings of nine percent of the annual cost of the CCCSD design. (It should be noted that the filter press information became available after the design of the CCCSD plant was completed. Solids processing using filter presses will be considered as an alternative in future plant expansions).

Cost of Reclaimed Lime Production vs. Purchased Lime

It is not an easy matter to separate the cost of lime recovery from the cost of solids disposal in the ATTF solids processing system. It could be argued that the thickening, dewatering and incineration steps are all required for sludge disposal and that the incremental cost of lime recovery is only the capital and O&M costs of the extra energy required to convert calcium carbonate to calcium

Table 12-7. OPERATION AND MAINTENANCE COST FOR LIME TREATMENT AND RECOVERY AT THE CCCSD WATER RECLAMATION PLANT

Item	Process	Cost item, dollar/year						
		Energy		Chemicals		Operating labor	Maintenance, repairs & supplies	Total O&M cost
		Power	Fuel	Lime	Polymer & other			
I	Chemical addition	500	-	173,400	-	3,900	5,500	183,300
II	Preaeration and grit removal	8,500	-	-	-	6,000	3,100	17,600
III	Primary sedimentation	2,600	-	-	-	16,700	3,700	23,000
IV	Sludge thickening	200	-	-	-	2,800	1,900	4,900
V	Wet classification	23,400	-	-	-	23,600	11,000	58,000
VI	Sludge dewatering[b]	25,700	-	-	38,300[a]	23,800	11,600	99,400
VII	Lime recalcination	38,300	12,100	-	-	25,500	43,900	119,800
VIII	Sludge incineration	36,500	53,200	-	-	26,200	45,800	161,700
IX	Related processes							
	a. Heat recovery	11,500	-	-	3,000	19,600	44,960	79,000
	b. Pneumatic conveying	11,000	-	-	-	10,900	35,600	57,500
Total O&M cost								804,200

[a] At 0.9 kg (2 lb) per ton DS

[b] Case 100, Section X

Table 12-8. OPERATION AND MAINTENANCE COST FOR ALTERNATE DEWATERING PROCESS AT THE CCCSD PLANT - VACUUM FILTERS

Item	Process	Cost item, dollar/year						
		Energy		Chemicals		Operating labor	Maintenance, repairs & supplies	Total O&M cost
		Power	Fuel	Lime	Polymer & other			
I	Chemical addition	500	-	183,100	-	3,900	5,500	193,000
II	Preaeration and grit removal	8,500	-	-	-	6,000	3,100	17,600
III	Primary sedimentation	2,600	-	-	-	16,700	3,700	23,000
IV	Sludge thickening	200	-	-	-	2,800	1,900	4,900
V	Sludge dewatering[a]	24,100	-	-	66,800[b]	45,500	11,500	147,900
VI	Lime recalcination[c]	74,800	122,700	-	-	51,700	87,800	337,000
VII	Related processes							
	a. Heat recovery	11,500	-	-	3,000	19,600	44,900	79,000
	b. Pneumatic conveying	11,000	-	-	-	10,900	35,600	57,500
Total O&M cost								859,900

[a] Case 114, Section X, Plural Purpose flow sheet.
[b] At 0.45 kg (1 lb) ton of DS.
[c] Two furnaces operating on Plural Purpose mode - 20 percent blowdown.

Table 12-9. OPERATION AND MAINTENANCE COST FOR ALTERNATE DEWATERINC PROCESS AT THE CCCSD PLANT - FILTER PRESSES

Item	Process	Cost item, dollar/year						
		Energy		Chemicals				
		Power	Fuel	Lime	Polymer & other	Operating labor	Maintenance, repairs & supplies	Total O&M cost
I	Chemical addition	500	-	173,400	-	3,900	5,500	183,300
II	Preaeration and grit removal	8,500	-	-	-	6,000	3,100	17,600
III	Primary sedimentation	2,600	-	-	-	16,700	3,700	23,000
IV	Sludge thickening	200	-	-	-	2,800	1,900	4,900
V	Wet classification[a]	23,400	-	-	-	23,600	11,000	58,000
IV	Sludge dewatering[a]	5,100	-	-	-	28,100	26,400	59,600
VII	Lime recalcination	38,300	11,800	-	-	25,500	43,900	119,500
VIII	Sludge incineration	36,500	21,300	-	-	26,200	45,800	129,800
IX	Related processes							
	a. Heat recovery	11,500	-	-	3,000	19,600	44,900	79,000
	b. Pneumatic conveying	11,000	-	-	-	10,900	35,600	57,500
Total O&M cost								732,200

[a] Case 102, Section X, ATTF Solids Processing System with pressure filtration in the second stage.

Table 12-10. FUEL REQUIREMENTS FOR ALTERNATIVE CASES

Item	ATTF system case with 2nd stage centrifuge (Case 100)				ATTF system case with 2nd stage filter press (Case 102)				Plural purpose with vacuum filter (Case 114) per furnace basis (2 furnaces required)	
	Recalcine furnace		Waste sludge furnace		Recalcine furnace		Waste sludge furnace			
Wet cake rate, kg/day (lb/day)	109,400 (241,000)		204,600 (450,700)		106,400 (234,400)		137,100 (302,000)		451,200 (993,880)	
Furnace loading rate, kg/sq m/hr (lb/sq ft/hr)	19	(3.9)	35.1	(7.2)	18.3	(3.75)	23.4	(4.8)	39	(8)
Gross heat inputs	kg-cal/hr	BTU/hr	kg-cal/hr	BTU/hr	kg-cal/hr	BTU/hr	kg-cal/hr	BTU/hr	kg-cal/hr	BTU/hr
Combustion of volatiles	2,453,918	9,737,770	2,857,172	11,337,984	2,383,920	9,460,000	3,172,252	12,588,300	2,644,356	10,493,475
Net-auxiliary fuel	2,105,992	8,357,113	5,839,287	23,171,773	2,045,736	8,118,000	3,404,362	13,509,372	6,310,310	25,040,912
Total	4,559,910	18,094,883	8,696,459	34,509,757	4,429,656	17,578,000	6,576,614	26,097,672	8,954,666	35,534,387
Heat accounted for										
Uses[a]	1,275,546	5,061,691	1,559,117	6,186,973	1,239,336	4,918,000	1,447,469	5,743,923	1,633,057	6,480,383
Total sensible heat in stack gases	3,284,364	13,033,192	7,137,342	28,322,784	3,190,320	12,660,000	5,129,145	20,353,749	7,321,609	29,054,004
	4,559,910	18,094,883	8,696,459	34,509,757	4,429,656	17,578,000	6,576,614	26,097,672	8,954,666	35,534,387
Heat recoverable in waste heat boiler[b]	2,397,609	9,514,320	5,210,259	20,675,632	2,328,984	9,242,000	3,744,275	14,858,236	5,344,787	21,209,472
Gross heat-auxiliary fuel[c]	3,275,669	12,998,688	9,082,451	36,041,473	3,182,004	12,627,000	5,295,158	21,012,533	9,815,083	38,948,739
	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr
Total gas required	287	632	795	1,752	279	614	464	1,021	859	1,893
Gas assigned to recalcination or incineration	77	169	339	746	75	165	136	299	391	861
Total gas assigned	kg/hr		lb/hr		kg/hr		lb/hr		kg/hr	lb/hr
to recalcination and incineration	416		915		211		464		782	1,722

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[a] Evaporation of water, radiation losses, shaft heating air, heat of reaction, heat loss in calcine product.

[b] Taken as 73 percent of total sensible heat of furnace off gases.

[c] Ratio to net heating value: 20,564/13,221 = 1.555402 (cf Section VIII).

[d] Calculated as the difference between the gross heat from auxiliary full less that recovered in the waste heat boiler, divided by the gross heat input times the total gas required; e.g., for the recalcine furnace in Case 100: 632 (12,998,688 - 9,514,320)/(12,998,688) = 169.

oxide plus the cost of operation of the dry classification step. On this basis, the cost of reclaimed lime would be low. Investigators at South Tahoe reasoned that the reclaimed lime cost was the total cost of the recalcining step, since lime sludge thickening and dewatering would be common to any lime coagulation process.[7] Costs for the example in this report are calculated on the same basis as for South Tahoe, and include only the recalcination step. The O&M and annual cost estimate for recalcination totals $388,200/yr. Since it was found that recalcined lime eliminated the need for the use of ferric chloride as a supplemental coagulant (Table 8-12), a savings of $63,800 can be credited to recalcination, leaving a balance of $324,400/yr. For this case, 8620 tons/yr of CaO are returned to the process. The unit cost of recalcination is $37.63 per ton of CaO. While it appears that recalcined lime costs 13 percent more than new lime, several other factors must be considered. First, the recent quotation of $33.20 per ton (100% CaO) has been made by the manufacturer with the cautionary statement that a significant increase in cost is expected in the near future. Second, a portion of the cost of recalcination could be attributed to ultimate disposal of the large quantity of calcium carbonate sludge generated by the process. On this basis, the cost of reclaimed lime is considered competitive with the cost of new lime for this case.

Table 12-11. COMPARISON OF TOTAL ANNUAL COSTS FOR LIME TREATMENT AND SOLIDS PROCESSING

System	Cost category, dollar/year		
	O&M	Annual cost of capital[d]	Total annual cost
CCCSD design[a] 1st: centrifuge 2nd: centrifuge	804,200	1,412,600	2,216,800
Plural Purpose[b] (vacuum filters)	859,400	1,435,800	2,295,200
Modified design[c] 1st: centrifuge 2nd: filter press	732,200	1,298,900	2,031,100

[a] Case 100, Section X
[b] Case 114, Section X
[c] Case 102, Section X
[d] CRF at 20 years and 6 percent = 0.08718456

Cost of Sludge Processing

The entire sequence of operations in the CCCSD Water Reclamation Plant, beginning with thickening and ending with the production of ash for ultimate disposal and reclaimed lime for reuse, can be considered the sludge processing system. The unit cost of operation for the total system expressed per ton of DS processed is of interest. The annual cost of capital for the system is \$1,265,000/yr, exclusive of Item I in Table 12-4. O&M cost totals \$580,300, exclusive of Items I, II and III in Table 12-7. Total annual cost is \$1,845,300/yr. A total of 33,490 tons/yr of new sludge is precipitated in the system, exclusive of recycled solids. Therefore, the unit cost of sludge processing is \$55,10/ton of DS. This cost is competitive with the cost of other sludge disposal systems. The cost can also be expressed per unit of wastewater treated; on this basis the cost is \$167/mil gal based on an average dry weather flow of 30 mgd.

SECTION XII

REFERENCES

1. Brown and Caldwell, Consulting Engineers. Report on Energy Requirements for Alternative Modes of Operation of Water Reclamation Plant. Prepared for the Central Contra Costa Sanitary District, Walnut Creek, California. 1974.

2. Flanagan, M.J. Direct Digital Control of Central Contra Costa Sanitary District Water Reclamation Plant. (Presented at IAWPR Specialized Conference, London). September, 1973. 12 p.

3. Caldwell Connell Engineers. Design Report - Lower Molonglo Water Quality Control Centre. Prepared for the National Capital Development Commission, Canberra, Australia. April, 1971.

4. Caldwell Connell Engineers. Revisions to Design Report - Lower Molonglo Water Quality Control Centre. Prepared for the National Capital Development Commission, Canberra, Australia. May, 1972.

5. Parker, D.S., K.E. Train, and F.J. Zadick. Sludge Processing for Combined Physical-Chemical-Biological Sludges. U.S. Environmental Protection Agency, Washington, D.C. Report No. EPAR2-73-250, July, 1973. 141 p.

6. Consulting Engineering - A Guide for the Engagement of Engineering Services. American Society of Civil Engineers, New York. ASCE Manual on Engineering Practice Number 45. July, 1972. 96 p.

7. Advanced Wastewater Treatment as practiced at South Tahoe. South Tahoe Public Utility District. Washington, D.C. Project 17010 ELQ. U.S. Environmental Protection Agency. August 1971. 436 p.

SECTION XIII

LIST OF INVENTIONS AND PUBLICATIONS

No inventions have resulted from this work, nor have any patent applications been made as a result of this work. All processes described in this work were state-of-the-art prior to inception of this project. To date (May, 1974) no publications have resulted from this work.

SECTION XIV

GLOSSARY

This glossary explains the various abbreviations used throughout the report; see Tables 10-1, 10-2, and 10-3 for symbols used in the computer program.

Btu	British thermal units
C	degrees Celsius
cfm	cubic feet per minute
cfs	cubic feet per second
cu ft	cubic foot (feet)
cu m	cubic meter
DS	dry solids
F	degree Farenheit
FBR	fluidized bed reactor
ft	foot (feet)
G	gravitational force per pound mass, feet per $(\text{second})^2$
gal	gallon (s)
gpd	gallons per day
gpm	gallons per minute
HHV	high heat value
in.	inch (es)
kg	kilogram (s)
kcal	kilocalories
L	bowl length, cm
l	liter (s)
lb	pound (s)
LHV	Low heat value
l/sec	liters per second
m	meter
mgd	million gallons per day
mg/l	milligram (s) per liter
MHF	multiple hearth furnace
ppm	part (s) per million
psi	pound (s) per square inch
R_1	radius of the liquid surface, cm
R_2	radius of the inner wall of the bowl, cm
RKC	rotary kiln calciner
Δ RPM	difference in revolutions per minute for centrifuge, Δ RPM is bowl speed minus conveyor speed
Σ	"sigma" factor
sq ft	square foot (feet)
sq in.	square inch (es)
sq m	square meter

SS	suspended solids
TS	total solids
VS	Volatile solids (or volatile matter)
w	rate of rotation, rad/sec
wt	weight

SECTION XV

APPENDICES

The attached appendix is in two parts. Appendix A contains a listing of the solids balance computer program, SOLIDS IA, which has been described in detail in Section X. Appendix B contains copies of the output from this program for 23 cases that were run for this project. Table B-1 is an index for these cases.

APPENDIX A

LISTING OF SOLIDS 1A

```
SOLIDS1A     11:50PDT     04/04/74

100C THIS IS A PROGRAM TO CALCULATE THE EQUILIBRIUM MASS BALANCES FOR
110C SEVERAL COMPONENTS IN A LIME SLUDGE PROCESSING SEQUENCE EMPLOYING
120C WET CLASSIFICATION,RECALCINATION,DRY CLASSIFICATION OF RECALCIN-
130C ED PRODUCT,DEWATERING AND INCINERATION OF CENTRATE SOLIDS FROM WET
140C CLASSIFICATION,WITH OPTIONS FOR BLOWDOWN OF RECALCINED PRODUCT,
150C OR SINGLE FURNACE CASE WITH NO DEWATERING AND INCINERATION STEPS.
160C IF FURNACE STACK LOSSES(RECOVERED IN THE WET SCRUBBER) ARE TO BE
170C RETURNED TO THE PRIMARY, THEN INPUT "SEREC" AS 1.0. IF THE WET
180C SCRUBBER EFFLUENT IS NOT TO BE RETURNED TO THE PRIMARY, THEN
190C INPUT "SEREC" AS 0.0
200C IF NO BLOWDOWN IS WANTED, THEN "FRBD" =0.0.
210C IF NO CLASSIFIER FOR RECALCINED PRODUCT IS WANTED,"CLASSIF"=0.0.
220C IF CLASSIFIER IS EMPLOYED, LET "CLASSIF" =1.0.
230C IF NO SECOND STAGE CENTRIFUGE AND INCINERATION FURNACE ARE USED,
240C LET "FURNACE" EQUAL 1.0; IF THEY ARE INCLUDED, LET "FURNACE"=2.0.
250C IF NO CLASSIFIER EMPLOYED, INPUT ALL COMPONENT CLASSIFIER RECOVERY
260C FRACTIONS AS 1.0,(TOTAL RECOVERY), EXCEPT ORGANICS, FE(OH)3, AND MG(OH)2
270C WHICH ARE ALL ZERO.
280C INPUT THE RECOVERIES OF ORGANICS, FE(OH)3, MG(OH)2 IN FURNACES
290C AND CLASSIFIER AS 0.0 FOR ALL CASES.
300C IF NO SECOND STAGE CENTRIFUGE OR INCINERATION FURNACE USED, LET THE
310C RECOVERY OF ALL COMPOUNDS IN THESE EQUAL ZERO.
320C PROGRAMMER: F.J. ZADICK,BROWN & CALDWELL, SAN FRANCISCO, CALIF.,FEB.,1974
330    FILELIST "DAT1","DAT2","DAT3"
340    110 FORMAT(V)
345
350C STATEMENT 224 IS USED TO SUPRESS DIAGNOSTICS DURING COMPILING
360    224 L=123+L
365
370C READ FROM FILES DAT1, DAT2, DAT3
380    225 READ(1,110)L,XMGD,XLBWASIN,FECL3MGL,CAHTODOS,FRBD,RECALEFF
390    227 READ(1,110)L,FURNACE,CLASSIF,PH,SEREC,FEINFMGL,SIINDMGL,SIEFDMGL
400    229 READ(2,110)L,SSINMGL,SSOUTMGL,XMGINMGL,XMGEFMGL,CAINFMGL,CAEFFMGL
410    231 READ(2,110)L,PINFMGL,PEFFMGL,FEEFFMGL,FRAIISSO,FRAIISSI
420    233 READ(2,110)L,FRSIWAS,FRAIIWAS,FRVWASIN,FRVSSIN,FRVSSOUT
430    235 READ(2,110)L,FRSISSI,FRSISSO,FRSINEW,FRAIINEW,FRMGONEW,FRCAONEW
440    237 READ(3,110)L,RECAP1,RECAC1,RESI1,REAII1
450    239 READ(3,110)L,REXMGH1,REXMGO1,REFEOH1,REFEO1,REORG1
460    241 READ(3,110)L,RECAP2,RECAC2,RESI2,REAII2,REFEOH2
470    243 READ(3,110)L,REFEO2,REORG2,REXMGH2,REXMGO2
480    245 READ(3,110)L,RECAPF,RECACF,RESIF,REAIIF,REFEOHF
490    247 READ(3,110)L,REFEOF,REORGF,REXMGHF,REXMGOF
500    249 READ(3,110)L,RECAPF1,RECACF1,RESIF1,REAIIF1,REFEOHF1
510    251 READ(3,110)L,REFEOF1,REORGF1,REXMGHF1,REXMGOF1
520    253 READ(3,110)L,RECAPCL,RECACCL,RESICL,REAIICL,REFEOHCL,RECACCL
530    255 READ(3,110)L,REFEOCL,REORGCL,REXMGHCL,REXMGOCL
540    800 XLBSSIN=XMGD*8.33*SSINMGL
550    803 XLBSSOUT=XMGD*8.33*SSOUTMGL
560    805 XMGINF=XMGD*8.33*XMGINMGL
570    807 XMGEFF=XMGD*8.33*XMGEFMGL
580    810 CAINF=XMGD*8.33*CAINFMGL
590    814 CAEFF=XMGD*8.33*CAEFFMGL
600    816 PINF=XMGD*8.33*PINFMGL
610    818 PEFF=XMGD*8.33*PEFFMGL
620    822 AIIEFF=XLBSSOUT*(FRAIISSO)
630    828 FEEFF=XMGD*8.33*FEEFFMGL
640        SIIND=SIINDMGL*8.33*XMGD
650        SIEFFD=SIEFDMGL*8.33*XMGD
660    826 SIEFF=XLBSSOUT*(FRSISSO)+SIEFFD
670    830 FECL3=XMGD*8.33*FECL3MGL
680    834 CAHTOTLB=CAHTODOS*XMGD*8.33
690    836 CAOTOTLB=CAHTOTLB*(56./74.)
700    837 CAOTOMGL=CAHTODOS*56./74.
705
710C CALCULATE FE(OH)3 IN PRIMARY SLUDGE
720    840 FEOHSLG=(((FECL3)*(107./162.5)+(FEINFMGL)*(107./56.)*(XMGD)*(
730       &8.33)-(FEEFF)*(107./56.))/(1.-(1.-REFEOH2)*(1.-REFEOH1))
735
740C CALCULATE FE(OH)3 IN OTHER LIQUID STREAMS
750    842 FEOH1P=(FECL3)*(107./162.5)-(FEEFF)*(107./56.)+(FEINFMGL)*(
760       &XMGD)*(8.33)*(107./56.)
770    844 FEOHCAK1=(REFEOH1)*(FEOHSLG)
780    850 FEOHCNT1=(FEOHSLG)-(FEOHCAK1)
790    853 FEOHCAK2=(FEOHCNT1)*(REFEOH2)
800    856 FEOHCNT2=(FEOHCNT1)*(1.-REFEOH2)
805
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```
C NO FE(OH)3 IN ASH STREAMS OR SCRUBBER WATER
  859 FEOHFP=0.0
  862 FEOHFPI=0.0
  864 FEOHRS=0.0
  867 FEOHBD=0.0
  870 FEOHCR=0.0

C FE(OH)3 NOT PRESENT IN EITHER FURNACE PRODUCT OR CLASSIFIER ACCEPTS
  873 REFEOHF=0.0
  876 REFEOHCL=0.0
  879 REFTOHFI=0.0
  880 FEOHSE1=0.0
  881 FEOHSE2=0.0
      IF(SEREC.EQ.0.0) GO TO 885

C CALCULATE FE2O3 IN PRIMARY SLUDGE
  883 FEOSLG=((FEOHCAK1)*(REFEOF)*(160./214.)*(1.-FRBD)*(REFEOCL)+(FEOH
     &CAK1)*(1.-REFEOF)*(160./214.)+(FEOHCAK2)*(1.-REFEOFI)*(160./214.)
     &)/(1.-(1.-REFEO1)*(1.-REFEO2)-(REFEO1)*(REFEOF)*(1.-FRBD)*(REFEOCL
     &)-(REFEO1)*(1.-REFEOF)-(1.-REFEO1)*(REFEO2)*(1.-REFEOFI))
      IF(SEREC.EQ.1.0) GO TO 895
  885 FEOSLG=((FEOHCAK1)*(REFEOF)*(160./214.)*(1.-FRBD)*(REFEOCL))/
     &(1.-(1.-REFEO1)*(1.-REFEO2)-(REFEO1)*(REFEOF)*(1.-FRBD)*(REF
     &EOCL))

C CALCUALTE FE2O3 IN OTHER STREAMS
  895 FEOCAK1=FEOSLG*(REFEO1)
  898 FEOCNT1=FEOSLG*(1.-REFEO1)
  901 FEOCAK2=FEOCNT1*(REFEO2)
  905 FEOCNT2=FEOCNT1*(1.-REFEO2)
  908 FEOFP=FEOCAK1*(REFEOF)+FEOHCAK1*(REFEOF)*(160./214.)
  910 FEOBD=FEOFP*(FRBD)
  911 FEO1P=0.0
  912 FEORS=FEOFP*(1.-FRBD)*(REFEOCL)
  914 FEOCR=FEOFP*(1.-FRBD)*(1.-REFEOCL)
  916 FEOFPI=FEOCAK2*(REFEOFI)+(FEOHCAK2)*(REFEOFI)
  917 FEOSE1=FEOCAK1*(1.-REFEOF)+(FEOHCAK1)*(1.-REFEOF)*(160./214.)
      IF(SEREC.EQ.0.0) GO TO 919

C CALCULATE CA3(PO4)2 IN PRIMARY SLUDGE
  918 CAPSLG=((PINF-PEFF)*(310./62.))/(1.-(1.-RECAP1)*(1.-RECAP2)-(RECA
     &P1)*(RECAPF)*(1.-FRBD)*(RECAPCL)-(RECAP1)*(1.-RECAPF)-(1.-RECAP1)
     &*(1.-RECAPFI)*(RECAP2))
      IF(SEREC.EQ.1.0) GO TO 921
  919 CAPSLG=((PINF-PEFF)*(310./62.))/(1.-(1.-RECAP1)*(1.-RECAP2)-(RECA
     &P1)*(RECAPF)*(1.-FRBD)*(RECAPCL))

C CALCULATE CA3(PO4)2 IN OTHER STREAMS
  921 CAP1P=(PINF-PEFF)*(310./62.)
  922 CAPCAK1=CAPSLG*(RECAP1)
  923 CAPFP=CAPCAK1*(RECAPF)
  925 CAPCNT1=CAPSLG*(1.-RECAP1)
  927 CAPCAK2=CAPCNT1*(RECAP2)
  929 CAPCNT2=CAPCNT1*(1.-RECAP2)
  931 CAPFPI=CAPCAK2*(RECAPFI)
  933 CAPBD=CAPFP*(FRBD)
  935 CAPRS=CAPFP*(1.-FRBD)*(RECAPCL)
  937 CAPCR=CAPFP*(1.-FRBD)*(1.-RECAPCL)
  939 CAPSE1=CAPCAK1*(1.-RECAPF)
  940 CAPSE2=CAPCAK2*(1.-RECAPFI)

C CALCULATE MG(OH)2 IN PRIMARY SLUDGE
  941 XMGHSLG=((XMGINF-XMGEFF)*(58.3/24.3))/(1.-(1.-REXMGH1)*(1.-REXMGH2
     &))

C CALCULATE MG(OH)2 IN OTHER STREAMS
  942 XMGH1P=(XMGINF-XMGEFF)*(58.4/24.3)
  943 XMGHCAK1=XMGHSLG*(REXMGH1)
  945 XMGHCNT1=XMGHSLG*(1.-REXMGH1)
  947 XMGHCAK2=(XMGHCNT1)*(REXMGH2)
  949 XMGHCNT2=(XMGHCNT1)*(1.-REXMGH2)

C NO MG(OH)2 IN ASH STREAMS
  951 XMGHFP=0.0
  953 XMGHRS=0.0
  955 XMGHBD=0.0
  957 XMGHFPI=0.0
  959 XMGHCR=0.0

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C NO MG(OH)2 PRESENT IN EITHER FURNACE PRODUCT OR CLASSIFIER ACCEPTS
  961 REXMGHF=0.0
  963 REXMGHFI=0.0
  965 REXMGHCL=0.0

C NO MG(OH)2 IN SCRUBBER WATER
  966 XMGHSE1=0.0
  967 XMGHSE2=0.0

C CALCULATE ORGANICS IN PRIMARY SLUDGE
  969 ORGSLG=((XLBSSIN)*(FRVSSIN)+(XLBWASIN)*(FRVWASIN)-(XLBSSOUT)*(FRVS
     &SOUT))/(1.-(1.-REORG1)*(1.-REORG2))

C CALCULATE ORGANICS IN OTHER LIQUID STREAMS
  972 ORGIP=(XLBSSIN)*(FRVSSIN)+(XLBWASIN)*(FRVWASIN)-XLBSSOUT*FRVSSOUT
  973 ORGCAK1=ORGSLG*(REORG1)
  975 ORGCNT1=ORGSLG*(1.-REORG1)
  977 ORGCAK2=ORGCNT1*(REORG2)
  979 ORGCNT2=ORGCNT1*(1.-REORG2)

C NO ORGANICS IN ASH STREAMS
  981 ORGFP=0.0
  983 ORGFP1=0.0
  985 ORGCR=0.0
  987 ORGBD=0.0
  989 ORGRS=0.0

C NO ORGANICS IN SCRUBBER WATER
  990 ORGSE1=0.0
  991 ORGSE2=0.0
  992 REORGF=0.0

C ORGANICS NOT PRESENT IN EITHER FURNACE PRODUCT OR SCRUBBER WATER
  993 REORGFI=0.0
  995 REORGCL=0.0

      IF(SEREC.EQ.0.0) GO TO 998

C CALCULATE CACO3 IN PRIMARY SLUDGE
  997 CACSLG=(((CAINF-CAEFF)*(100./40.)+(CAOTOTLB)*(100./56.)-(PINF-PEFF)
     &*(120./62.0)*(100./40.))/(1.-(RECAC1)*(RECACF)*(1.-FRBD)*(RECACCL)
     &*(1.-RECALEFF)-(1.-RECAC1)*(1.-RECAC2)-(RECAC1)*(1.-RECACF)-(1.-RE
     &CAC1)*(RECAC2)*(1.-RECACF1))
      IF(SEREC.EQ.1.0) GO TO 1000
  998 CACSLG=(((CAINF-CAEFF)*(100./40.)+(CAOTOTLB)*(100./56.)-(PINF-PEFF)
     &*(120./62.0)*(100./40.))/(1.-(RECAC1)*(RECACF)*(1.-FRBD)*(RECACCL)
     &*(1.-RECALEFF)-(1.-RECAC1)*(1.-RECAC2))

C CALCULATE CACO3 IN OTHER STREAMS
 1000 CACIP=(CAINF-CAEFF)*(100./40.)+CAOTOTLB*(100./56.)-(PINF-PEFF)*(1
     &20./62.)*(100./40.)
 1001 CACCAK1=CACSLG*(RECAC1)
 1002 CACFP=(RECACF)*(CACCAK1)*(1.-RECALEFF)
 1004 CACCNT1=CACSLG*(1.-RECAC1)
 1007 CACCAK2=CACCNT1*(RECAC2)
 1009 CACCNT2=CACCNT1*(1.-RECAC2)
 1011 CACFP1=CACCAK2*(RECACF1)
 1012 CACSE1=(CACCAK1)*(1.-RECACF)
 1013 CACSE2=CACCAK2*(1.-RECACF1)
 1015 CACBD=CACFP*(FRBD)
 1017 CACRS=CACFP*(1.-FRBD)*(RECACCL)
 1018 CACCR=CACFP*(1.-FRBD)*(1.-RECACCL)

C CALCULATE CAO IN RECALCINATION FURNACE PRODUCT
 1019 CAOFP=CACCAK1*(RECACF)*(RECALEFF)*(56./100.)

C CALCULATE CAO IN THE BLOWDOWN AND CLASSIFIER STREAMS
 1021 CAOBD=(CAOFP)*(FRBD)
 1023 CAORS=CAOFP*(1.-FRBD)*(RECAOCL)
 1025 CAOCR=CAOFP*(1.-FRBD)*(1.-RECAOCL)

C CALCULATE NEW LIME REQUIRED
 1027 CAONEW=CAOTOTLB-CAORS

C NO CAO IN RECALCINE FURNACE SCRUBBER WATER
 1028 CAOSE1=0.0

C NO CAO IN INCINERATION FURNACE WASTE ASH
 1029 RECAOFI=0.0
 1031 TOTLBNEW=CAONEW/FRCAONEW

C NO CAO IN SECOND STAGE DEWATERING STREAMS
 1033 RECAO2=0.0
 1035 CAONMGL=(CAONEW)/(8.33*XMGD)
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2200C NO CAO IN FIRST STAGE DEWATERING STREAMS
2210  1037 RECAO1=0.0
2220  1039 CAORMGL=(CAORS)/(8.33*XMGD)
2225
2230C NO CAO IN SECOND STAGE CENTRATE
2240  1041 CAOCNT2=0.0
2250  1042 SUMDOS=CAONMGL+CAORMGL
2260  1044 CAORSFRA=CAORMGL/SUMDOS
2265
2270C NO CAO IN LIQUID STREAMS
2280  1047 CAOCAK2=0.0
2290  1048 CAO1P=0.0
2300  1049 CAOSLG=0.0
2310  1051 CAOCAK1=0.0
2320  1055 CAOCNT1=0.0
2330  1056 CAOSE2=0.0
2335
2340C NO CAO IN INCINERATION FURNACE WASTE ASH
2350  1057 CAOFPI=0.0
2355
2360C SUM THE SOURCES OF ACID INSOL.INERTS(EXCEPT SILICA INTO THE PRIMARY ON FIRST PASS
2370  1061 AIIIN=      (TOTLBNEW)*(FRAIINEW)+(XLBSSIN)*(FRAIISSI)+(XLBWASIN)*
2380      &(FRAIIWAS)
2385
2390C CALCULATE ACID INSOL.INERTS PRECIPITATED ON FIRST PASS
2400        AII1P=AIIIN-AIIEFF
2410  1062 AIIINMGL=AIIIN/(8.33*XMGD)
2420        IF(SEREC.EQ.0.0) GO TO 1064
2425
2430C CALCULATE ACID INSOL.INERTS IN PRIMARY SLUDGE
2440  1063 AIISLG=((AIIIN)-(AIIEFF))/(1.-(1.-REAII1)*(1.-REAII2)-(REAII1)*(RE
2450      &AIIF)*(1.-FRBD)*(REAIICL)-(1.-REAII1)*(REAII2)*(1.-REAIIF1)-(REAII
2460      &1)*(1.-REAIIF))
2470        IF(SEREC.EQ.1.0) GO TO 1065
2480  1064 AIISLG=((AIIIN-AIIEFF))/(1.-(1.-REAII1)*(1.-REAII2)-(REAII1)*(RE
2490      &AIIF)*(1.-FRBD)*(REAIICL))
2495
2500C CALCULATE ACID INSOL.INERTS IN OTHER STREAMS
2510  1065 AIIFP=(AIISLG)*(REAII1)*(REAIIF)
2520  1067 AIICAK1=(AIISLG)*(REAII1)
2530  1071 AIICNT1=(AIISLG)*(1.-REAII1)
2540  1073 AIICAK2=(AIICNT1)*(REAII2)
2550  1075 AIICNT2=(AIICNT1)*(1.-REAII2)
2560  1077 AIIBD=(AIIFP)*(FRBD)
2570  1079 AIIRS=(AIIFP)*(1.-FRBD)*(REAIICL)
2580  1081 AIIFP1=(AIICAK2)*(REAIIF1)
2590  1083 AIICR=(AIIFP)*(1.-FRBD)*(1.-REAIICL)
2600        AIIEFMGL=AIIEFF/(8.33*XMGD)
2610  1084 AIISE1=AIICAK1*(1.-REAIIF)
2615
2620C SUM THE SOURCES OF SIO2 INTO THE PRIMARY ON THE FIRST PASS
2630  1085 SIIN=      (XLBSSIN)*(FRSISSI)+(XLBWASIN)*(FRSIWAS)+(TOTLBNEW)*(FRS
2640      &INEW)+(SIINO)
2645
2650C CALCULATE SIO2 PRECIPITATED ON THE FIRST PASS
2660        SIO21P=SIIN-SIEFF
2670  1086 SIINMGL=SIIN/(8.33*XMGD)
2680        IF(SEREC.EQ.0.0) GO TO 1088
2685
2690C CALCULATE SIO2 IN THE PRIMARY SLUDGE
2700  1087 SISLG=((SIIN)-(SIEFF))/(1.-(1.-RESI1)*(1.-RESI2)-(RESI1)*(RESIF)*(
2710      &1.-FRBD)*(RESICL)-(1.-RESI1)*(RESI2)*(1.-RESIF1)-(RESI1)*(1.-RESIF
2720      &))
2730        IF(SEREC.EQ.1.0) GO TO 1089
2740  1088 SISLG=((SIIN)-(SIEFF))/(1.-(1.-RESI1)*(1.-RESI2)-(RESI1)*(RESIF)*(
2750      &1.-FRBD)*(RESICL))
2760  1089 SIEFFMGL=SIEFF/(8.33*XMGD)
2765
2770C CALCULATE SIO2 IN OTHER STREAMS
2780  1090 SIFP=(SISLG)*(RESI1)*(RESIF)
2790  1091 SICAK1=(SISLG)*(RESI1)
2800  1093 SICNT1=(SISLG)*(1.-RESI1)
2810  1095 SICAK2=(SICNT1)*(RESI2)
2820  1097 SICNT2=(SICNT1)*(1.-RESI2)
2830  1099 SIBD=(SIFP)*(FRBD)
2840  1101 SIRS=(SIFP)*(1.-FRBD)*(RESICL)
2850  1103 SIFPI=(SICAK2)*(RESIF1)
2860  1105 SICR=(SIFP)*(1.-FRBD)*(1.-RESICL)
2870  1106 SISE1=SICAK1*(1.-RESIF)
2875
2880C CALCULATE MGO INPUT FROM NEW LIME
2890  1107 XMGONEW=(FRMGONEW)*(TOTLBNEW)
2900  1108 XMGO1P=XMGONEW
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      IF(SEREC.EQ.0.0) GO TO 1110

C CALCULATE MGO IN PRIMARY SLUDGE
 1109 XMGOSLG=((XMGHCAK1)*(REXMGOF)*(1.-FRBD)*(REXMGOCL)*(40./58.3)+(1.
     &-REXMGOF)*(XMGHCAK1)*(40./58.3)+(XMGONEW)+(1.-REXMGOF1)*(XMGHCAK2
     &)*(40./58.3))/(1.-(1.-REXMGO1)*(1.-REXMGO2)-(REXMGO1)*(REXMGOF)*(R
     &EXMGOCL)*(1.-FRBD)-(1.-REXMGOF)*(REXMGO1)-(1.-REXMGO1)*(REXMGO2)*(
     &1.-REXMGOF1))
      IF(SEREC.EQ.1.0) GO TO 1111
 1110 XMGOSLG=((XMGHCAK1)*(REXMGOF)*(1.-FRBD)*(REXMGOCL)*(40./58.3)
     &+(XMGONEW))/(1.-(1.-REXMGO1)*(1.-REXMGO2)-(REXMGO1)*(REXMGOF)*(R
     &EXMGOCL)*(1.-FRBD))

C CALCULATE MGO IN OTHER STREAMS
 1111 XMGOCAK1=XMGOSLG*(REXMGO1)
 1113 XMGOCNT1=XMGOSLG*(1.-REXMGO1)
 1115 XMGOCAK2=XMGOCNT1*(REXMGO2)
 1117 XMGOCNT2=XMGOCNT1*(1.-REXMGO2)
 1119 XMGOFP=XMGOCAK1*(REXMGOF)+XMGHCAK1*(REXMGOF)*(40./58.3)
 1121 XMGOBD=XMGOFP*(FRBD)
 1123 XMGORS=XMGOFP*(1.-FRBD)*(REXMGOCL)
 1125 XMGOCR= XMGOFP*(1.-FRBD)*(1.-REXMGOCL)
 1127 XMGOFP1=XMGOCAK2*(REXMGOF1)+(XMGHCAK2)*(REXMGOF1)
 1129 XMGOSE1=(XMGOCAK1)*(1.-REXMGOF)+(XMGHCAK1)*(1.-REXMGOF)*(40./58.3)
 1130 XMGOSE2=XMGOCAK2*(1.-REXMGOF1)+XMGHCAK2*(1.-REXMGOF1)*(40./58.3)
 1132 FEOSE2=FEOCAK2*(1.-REFEOF1)+(FEOHCAK2)*(1.-REFEOF1)*(160./214.)
 1133 SISE2=SICAK2*(1.-RESIF1)
 1134 AIISE2=AIICAK2*(1.-REAIIF1)
 1135 TOT1=ORGSLG+CACSLG+XMGOSLG+XMGHSLG+FEOSLG+FEOHSLG+SISLG+AIISLG+C
     &APSLG
 1136 TOT2=ORGCAK1+CACCAK1+XMGOCAK1+XMGHCAK1+FEOCAK1+FEOHCAK1+SICAK1+A
     &IICAK1+CAPCAK1
 1137 TOT3=TOT1-TOT2
 1138 TOT4=CAOFP+CACFP+XMGOFP+FEOFP+SIFP+AIIFP+CAPFP
 1139 TOT5=CACSE1+XMGOSE1+FEOSE1+CAPSE1+SISE1+AIISE1
 1140 TOT6=CAORS+CACRS+XMGORS+FEORS+SIRS+AIIRS+CAPRS
 1141 TOT7=ORGCAK2+CACCAK2+XMGOCAK2+XMGHCAK2+FEOHCAK2+FEOCAK2+SICAK2+AI
     &ICAK2+CAPCAK2
 1142 TOT8=TOT3-TOT7
 1143 TOT9=CACFP1+XMGOFP1+FEOFP1+SIFP1+AIIFP1+CAPFP1
 1144 TOT10=CACSE2+XMGOSE2+FEOSE2+CAPSE2+SISE2+AIISE2
 1145 TOT11=TOT4*(FRBD)
 1146 TOT12=CAOCR+CACCR+XMGOCR+FEOCR+SICR+AIICR+CAPCR
 1147 TOTRE1=TOT2/TOT1
 1148 TOTRE2=TOT7/TOT3
 1149 TOTRECL=TOT6/(TOT6+TOT12)
 1150 TOT13=CAP1P+XMGH1P+FEOH1P+ORG1P+SIO21P+AII1P+CAC1P+CAO1P+FEO1P+XM
     &GO1P
  300 FORMAT(36H LIME SOLIDS PROCESSING MASS BALANCE)
  301 FORMAT(1H-)
  310 FORMAT(50H *   *FLOW*              LIME USE AS CAO             *)
  315 FORMAT(50H *PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*)
  320 FORMAT(50H                 MG/L       MG/L      MG/L    FRACTION )
  321 FORMAT(F5.1,1X,F6.2,2X,F5.1,5X,F5.1,5X,F5.1,5X,F4.2)
  340 FORMAT(37H *FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*)
  350 FORMAT(37H *     MG/L   *     ADDED,LB/DAY       *)
  353 FORMAT(4X,F6.1,11X,F9.1)
  354 FORMAT(1H-,//45H *FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*)
  355 FORMAT(1H-,//61H *RECALCINATION FURNACE WET SCRUBBER WATER COMPONE
     &NTS,LB/DAY*)
  356 FORMAT(1H-,//60H *INCINERATION FURNACE WET SCRUBBER WATER COMPONE
     &NTS,LB/DAY*)
  360 FORMAT(42H *FURNACE BLOWDOWN*RECALCINING EFFICIENCY*)
  365 FORMAT(42H *    FRACTION     *          FRACTION       *)
  367 FORMAT(8X,F5.2,16X,F5.2)
  415 FORMAT(1H-,35H *PRIMARY SLUDGE COMPONENTS,LB/DAY*)
  420 FORMAT(1H-,/9H ORGANICS,16X,F9.0,1H ,/4H CAO,21X,F9.0,1H ,/6H CACO
     &3,19X,F9.0,1H ,/4H MGO,21X,F9.0,1H ,/8H MG(OH)2,17X,F9.0,1H ,/6H F
     &E2O3,19X,F9.0,1H ,/8H FE(OH)3,17X,F9.0,1H ,/5H SIO2,20X,F9.0,1H ,
     &/19H ACID INSOL. INERTS,6X,F9.0,1H ,/10H CA3(PO4)2,15X,F9.0,//6H T
     &OTAL,17X,F11.0)
  400 FORMAT(1H-,//64H *                            PRIMARY EFFLUENT COMPOSITION,MG/L
     &             *)
  410 FORMAT(64H *SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INE
     &RTS*IRON*)
  411 FORMAT(5X,F5.1,6X,F5.1,4X,F5.1,4X,F6.2,3X,F5.1,2X,F5.1,2X,F6.2)
  430 FORMAT(1H-,//37H *FIRST STAGE CAKE COMPONENTS,LB/DAY*)
  440 FORMAT(1H-,//50H *RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*
     &)
  450 FORMAT(1H-,//41H *FIRST STAGE CENTRATE COMPONENTS,LB/DAY*)
  460 FORMAT(1H-,//38H *SECOND STAGE CAKE COMPONENTS,LB/DAY*)
  470 FORMAT(1H-,//50H *SECOND STAGE CENTRATE RECYCLE COMPONENTS,LB/DAY*
     &)
 480 FORMAT(1H-,//51H =INCINERATION FURNACE WASTE ASH COMPONENTS,LB/DAY
    &=)
 490 FORMAT(1H-,//51H =RECALCINATION FURNACE BLOWDOWN COMPONENTS,LB/DAY
    &=)
 495 FORMAT(1H-,//44H =RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY=)
 500 FORMAT(1H-,//39H =CLASSIFIER REJECTS COMPONENTS,LB/DAY=)
 505 FORMAT(1H-,//55H =RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRAC
    &TION=)
 508 FORMAT(55H                FIRST = RECALCINE =SECOND=INCINERATION=  DRY)
 510 FORMAT(55H                STAGE                 STAGE                    )
 515 FORMAT(60H                CAKE      FURNACE     CAKE      FURNACE     CLASSI
    &FIER)
 518 FORMAT(1H1,/9H ORGANICS,3X,F4.2,7X,F4.2,5X,F4.2,6X,F4.2,7X,F4.2)
 520 FORMAT(1H1,/4H CAO,8X,F4.2,7X,F4.2,5X,F4.2,6X,F4.2,7X,F4.2)
 522 FORMAT(1H1,/6H CACO3,6X,F4.2,7X,F4.2,5X,F4.2,6X,F4.2,7X,F4.2)
 525 FORMAT(1H1,/4H MGO,8X,F4.2,7X,F4.2,5X,F4.2,6X,F4.2,7X,F4.2)
 530 FORMAT(1H1,/8H MG(OH)2,4X,F4.2,7X,F4.2,5X,F4.2,6X,F4.2,7X,F4.2)
 535 FORMAT(1H1,/6H FE2O3,6X,F4.2,7X,F4.2,5X,F4.2,6X,F4.2,7X,F4.2)
 540 FORMAT(1H1,/8H FE(OH)3,4X,F4.2,7X,F4.2,5X,F4.2,6X,F4.2,7X,F4.2)
 545 FORMAT(1H1,/5H SIO2,7X,F4.2,7X,F4.2,5X,F4.2,6X,F4.2,7X,F4.2)
 550 FORMAT(1H1,/7H INERTS,5X,F4.2,7X,F4.2,5X,F4.2,6X,F4.2,7X,F4.2)
 551 FORMAT(1H1,/10H CA3(PO4)2,2X,F4.2,7X,F4.2,5X,F4.2,6X,F4.2,7X,F4.2)
 553 FORMAT(1H1,/6H TOTAL,6X,F4.2,16X,F4.2,17X,F4.2)
 560 FORMAT(1H1,64H=NEW MAKEUP LIME ADDED,FRACTION COMPOSITION=)
 570 FORMAT(1H1,64H= SIO2   = ACID INSOL. INERTS  = MGO  =CAO =)
 573 FORMAT(2X,F5.2,9X,F5.2,11X,F5.2,2X,F5.2)
 620 FORMAT(1H-,//64H =                    PRIMARY INFLUENT COMPOSITION,MG/L
    &            =)
 630 FORMAT(64H =SUSP.SOLIDS=MAGNESIUM=CALCIUM=PHOSPHORUS=SIO2=A.I.INE
    &RTS=IRON=)
 633 FORMAT(5X,F5.1,6X,F5.1,4X,F5.1,4X,F6.2,3X,F5.1,2X,F5.1,2X,F6.2)
1199 PRINT 301
1200 PRINT 300
1201 PRINT 301
1205 PRINT 310
1210 PRINT 315
1215 PRINT 320
1220 PRINT 321,PH,XMGD,CAOTOMGL,CAONMGL,CAORMGL,CAORSFRA
1221 PRINT 301
1225 PRINT 340
1240 PRINT 350
1250 PRINT  353,FECL3MGL,XLBWASIN
1251 PRINT 301
1260 PRINT 360
1270 PRINT 365
1280 PRINT 367,FRBD,RECALEFF
1281 PRINT 301
1290 PRINT 560
1300 PRINT 570
1310 PRINT 573,FRSINEW,FRAIINEW,FRMGONEW,FRCAONEW
1311 PRINT 301
1390 PRINT 620
1400 PRINT 630
1410 PRINT 633,SSINMGL,XMGINMGL,CAINFMGL,PINFMGL,SIINMGL,AIIINMGL,FEINFMGL
1420 PRINT 400
1430 PRINT 410
1432 PRINT 411,SSOUTMGL,XMGEFMGL,CAEFFMGL,PEFFMGL,SIEFFMGL,AIIEFMGL,
    &FEEFFMGL
1433 PRINT 301
1434 PRINT 354
1435 PRINT 420,ORG1P,CAO1P,CAC1P,XMGO1P,XMGH1P,FEO1P,FEOH1P,SIO21P,
    &AII1P,CAP1P,TOT13
1436 PRINT 301
1440 PRINT 415
1450 PRINT 420,ORGSLG,CAOSLG,CACSLG,XMGOSLG,XMGHSLG,FEOSLG,FEOHSLG,SISL
    &G,AIISLG,CAPSLG,TOT1
1453 PRINT 301
1460 PRINT 430
1470 PRINT 420,ORGCAK1,CAOCAK1,CACCAK1,XMGOCAK1,XMGHCAK1,FEOCAK1,FEOHCA
    &K1,SICAK1,AIICAK1,CAPCAK1,TOT2
1473 PRINT 301
1475 PRINT 450
1476 PRINT 420,ORGCNT1,CAOCNT1,CACCNT1,XMGOCNT1,XMGHCNT1,FEOCNT1,FEOHCN
    &T1,SICNT1,AIICNT1,CAPCNT1,TOT3
1477 PRINT 301
1480 PRINT 440
1490 PRINT 420,ORGFP,CAOFP,CACFP,XMGOFP,XMGHFP,FEOFP,FEOHFP,SIFP,AIIFP
    &CAPFP,TOT4
1492 PRINT 301
1493 PRINT 355
1494 PRINT 420,ORGSE1,CAOSE1,CACSE1,XMGOSE1,XMGHSE1,FEOSE1,FEOHSE1,SISE
```

```
     &1,AIISE1,CAPSE1,TOT5
1495 PRINT 301
1496 PRINT 495
1497 PRINT 420,ORGRS,CAORS,CACRS,XMGORS,XMGHRS,FEORS,FEOHRS,SIRS,AIIRS,
     &CAPRS,TOT6
1498 PRINT 301
1499 IF(IIBRAKE.EQ.1.0) GO TO 1600.
1500 PRINT 460
1510 PRINT 420,ORGCAK2,CAOCAK2,CACCAK2,XMGOCAK2,XMGHCAK2,FEOCAK2,FEOHCA
     &K2,SICAK2,AIICAK2,CAPCAK2,TOT7
1511 CONTINUE
1513 PRINT 301
1560 PRINT 470
1570 PRINT 420,ORGCNT2,CAOCNT2,CACCNT2,XMGOCNT2,XMGHCNT2,FEOCNT2,FEOHCN
     &T2,SICNT2,AIICNT2,CAPCNT2,TOT8
1575 PRINT 301
1580 PRINT 480
1590 PRINT 420,ORGFP1,CAOFP1,CACFP1,XMGOFP1,XMGHFP1,FEOFP1,FEOHFP1,SIFP
     &1,AIIFP1,CAPFP1,TOT9
1595 PRINT 301
1596 PRINT 356
1597 PRINT 420,ORGSE2,CAOSE2,CACSE2,XMGOSE2,XMGHSE2,FEOSE2,FEOHSE2,SISE
     &2,AIISE2,CAPSE2,TOT10
1598 PRINT 301
1599 CONTINUE
1600 IF(FRBD.EQ.0.0) GO TO 1617
1601 PRINT 490
1603 PRINT 420,ORGBD,CAOBD,CACBD,XMGOBD,XMGHBD,FEOBD,FEOHBD,SIBD,AIIBD,
     &CAPBD,TOT11
1617 CONTINUE
1620 IF(CLASSIF.EQ.0.0) GO TO 1650
1630 PRINT 500
1640 PRINT 420,ORGCR,CAOCR,CACCR,XMGOCR,XMGHCR,FEOCR,FEOHCR,SICR,AIICR,
     &CAPCR,TOT12
1643 PRINT 301
1650 PRINT 505
1652 PRINT 301
1660 PRINT 508
1670 PRINT 510
1680 PRINT 515
1690 PRINT 518,REORG1,REORGF,REORG2,REORGF1,REORGCL
1695 PRINT 520,RECAO1,RECACF,RECAO2,RECAOF1,RECAOCL
1700 PRINT 522,RECAC1,RECACF,RECAC2,RECACF1,RECACCL
1710 PRINT 525,REXMGO1,REXMGOF,REXMGO2,REXMGOF1,REXMGOCL
1720 PRINT 530,REXMGH1,REXMGHF,REXMGH2,REXMGHF1,REXMGHCL
1730 PRINT 535,REFEO1,REFEOF,REFEO2,REFEOF1,REFEOCL
1740 PRINT 540,REFEOH1,REFEOHF,REFEOH2,REFEOHF1,REFEOHCL
1750 PRINT 545,RESI1,RESIF,RESI2,RESIF1,RESICL
1760 PRINT 550,REAII1,REAIIF,REAII2,REAIIF1,REAIICL
1761 PRINT 551,RECAP1,RECAPF,RECAP2,RECAPF1,RECAPCL
1762 PRINT 553,TOTRE1,TOTRE2,TOTRECL
1763 CONTINUE
1800 STOP;END
```

APPENDIX B

OUTPUT FOR CASES

Table B-1. CASE DESCRIPTIONS

Case no.[a]	First stage wet classification	Second stage dewatering	Incineration of second stage cake	Classifier for recalcined product	Blowdown of recalcination fumace product, percent
100[b]	Centrifuge	Centrifuge	Yes	Yes	0
101[b]	Centrifuge	Vacuum filter	Yes	Yes	0
102[b]	Centrifuge	Pressure filter	Yes	Yes	0
103[c]	Centrifuge	None	No	Yes	0
104[c]	Centrifuge	None	No	Yes	10
105[c]	Centrifuge	None	No	Yes	15
106[c]	Centrifuge	None	No	Yes	20
107[c]	Centrifuge	None	No	Yes	24
108[c]	Centrifuge	None	No	Yes	28
109[c]	Centrifuge	None	No	Yes	31
110[c]	Centrifuge	None	No	Yes	35
111[c]	Centrifuge	None	No	Yes	45
112[c]	Centrifuge	None	No	Yes	100
113[c]	Vacuum filter	None	No	Yes	0
114[c]	Vacuum filter	None	No	Yes	20
115[c]	Pressure filter	None	No	Yes	0
116[c]	Pressure filter	None	No	Yes	20
117[b]	Centrifuge	Centrifuge	Yes	No	0
118[b]	Centrifuge	Centrifuge	Yes	No	20
119[b]	Centrifuge	Centrifuge	Yes	No	24
120[b]	Centrifuge	Centrifuge	Yes	No	28
121[b,d]	Centrifuge	Centrifuge	Yes	Yes	0
122[b,e]	Centrifuge	Centrifuge	Yes	Yes	0

[a] All cases are for the following conditions (unless noted):

pH: 11.0
Primary flow: 1.31 cu m/sec
$FeCl_3$ dose to primary: 14.0 mg/l
$Ca(OH)_2$ dose: 400.0 mg/l

[b] ATTF System case

[c] Plural Purpose Fumace case

[d] pH 10.2, 289 mg/l $Ca(OH)_2$, 24.0 mg/l $FeCl_3$

[e] pH 11.5, 500 mg/l $Ca(OH)_2$, 0.0 mg/l $FeCl_3$

```
CASE 100

DAT1

110,30.0,9746.0,14.0,400.0,0.0,0.95
115,2.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.09

DAT3

161,0.20,0.825,0.90,0.77
171,0.27,0.27,0.30,0.30,0.40
181,0.90,0.99,0.97,0.81,0.90
182,0.90,0.78,0.90,0.90
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.94,0.93,0.98,0.87,0.0
202,0.95,0.0,0.0,0.92
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966



LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*            LIME USE AS CAO           *
*PH * MGD*TOTAL DOSE*NEW LIME* RECYCLED    LIME*
              MG/L      MG/L      MG/L    FRACTION
11.0  30.00  302.7     113.7     189.0     0.62


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *     ADDED,LB/DAY      *
     14.0              9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *       FRACTION       *
       0.                  0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01              0.07   0.89



*                  PRIMARY INFLUENT COMPOSITION,MG/L                  *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0       22.3     30.0     10.00     13.2   1.9    0.


*                  PRIMARY EFFLUENT COMPOSITION,MG/L                  *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0        8.7     60.0      0.68     0.9    0.1    0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*

ORGANICS                        50540.
CAO                                 0.
CACO3                          105069.
MGO                              2234.
MG(OH)2                          8144.
FE2O3                               0.
FE(OH)3                          2304.
SIO2                             3075.
ACID INSOL. INERTS                458.
CA3(PO4)2                       11645.

TOTAL                          183509.


*PRIMARY SLUDGE COMPONENTS,LB/DAY*

ORGANICS                        58272.
CAO                                 0.
CACO3                          117972.
MGO                              6729.
MG(OH)2                          8770.
FE2O3                             851.
FE(OH)3                          2477.
SIO2                            10053.
ACID INSOL. INERTS               2185.
CA3(PO4)2                       17003.

TOTAL                          224312.


*FIRST STAGE CAKE COMPONENTS,LB/DAY*

ORGANICS                        23309.
CAO                                 0.
CACO3                           97327.
MGO                              1817.
MG(OH)2                          2368.
FE2O3                             255.
FE(OH)3                           743.
SIO2                             9047.
ACID INSOL. INERTS               1683.
CA3(PO4)2                        3401.

TOTAL                          139950.


*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*

ORGANICS                        34963.
CAO                                 0.
CACO3                           20645.
MGO                              4912.
MG(OH)2                          6402.
FE2O3                             596.
FE(OH)3                          1734.
SIO2                             1005.
ACID INSOL. INERTS                503.
CA3(PO4)2                       13603.

TOTAL                           84363.


*RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*

ORGANICS                            0.
CAO                             48154.
CACO3                            4526.
MGO                              3166.
MG(OH)2                             0.
FE2O3                             770.
FE(OH)3                             0.
SIO2                             8866.
ACID INSOL. INERTS               1464.
CA3(PO4)2                        3197.

TOTAL                           70143.
```

```
*RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY*

ORGANICS                        0.
CAO                             0.
CACO3                        6813.
MGO                           275.
MG(OH)2                         0.
FE2O3                          41.
FE(OH)3                         0.
SIO2                          181.
ACID INSOL. INERTS            219.
CA3(PO4)2                     204.

TOTAL                        7733.
```

```
*RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY*

ORGANICS                        0.
CAO                         47239.
CACO3                        4453.
MGO                          3059.
MG(OH)2                         0.
FE2O3                         666.
FE(OH)3                         0.
SIO2                         6747.
ACID INSOL. INERTS           1360.
CA3(PO4)2                    3059.

TOTAL                       66583.
```

```
*SECOND STAGE CAKE COMPONENTS,LB/DAY*
ORGANICS                    27271.
CAO                             0.
CACO3                       20439.
MGO                          4421.
MG(OH)2                      5762.
FT2O3                         536.
FE(OH)3                      1561.
SIO2                          975.
ACID INSOL. INERTS            407.
CA3(PO4)2                   12242.

TOTAL                       73614.
```

```
*SECOND STAGE CENTRATE RECYCLE COMPONENTS,LB/DAY*

ORGANICS                     7692.
CAO                             0.
CACO3                         206.
MGO                           491.
MG(OH)2                       640.
FE2O3                          60.
FE(OH)3                       173.
SIO2                           30.
ACID INSOL. INERTS             96.
CA3(PO4)2                    1360.

TOTAL                       10749.
```

```
*INCINERATION FURNACE WASTE ASH COMPONENTS,LB/DAY*

ORGANICS                        0.
CAO                             0.
CACO3                       19008.
MGO                          9369.
MG(OH)2                         0.
FE2O3                        1992.
FE(OH)3                         0.
SIO2                          956.
ACID INSOL. INERTS            354.
CA3(PO4)2                   11508.

TOTAL                       43186.
```

```
*INCINERATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY*

 ORGANICS                       0.
 CAO                            0.
 CACO3                       1431.
 MGO                          670.
 MG(OH)2                        0.
 FE2O3                         85.
 FE(OH)3                        0.
 SIO2                          20.
 ACID INSOL. INERTS            53.
 CA3(PO4)2                    735.

 TOTAL                       2993.
```

```
*CLASSIFIER REJECTS COMPONENTS,LB/DAY*

ORGANICS                        0.
CAO                           915.
CACO3                          72.
MGO                           108.
MG(OH)2                         0.
FE2O3                         105.
FE(OH)3                         0.
SIO2                         2119.
ACID INSOL. INERTS            104.
CA3(PO4)2                     137.

TOTAL                        3560.
```

```
*RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION*


          FIRST * RECALCINE *SECOND*INCINERATION*  DRY
          STAGE             STAGE
          CAKE    FURNACE   CAKE    FURNACE     CLASSIFIER

ORGANICS   0.40     0.       0.78    0.          0.

CAO        0.       0.93     0.      0.          0.98

CACO3      0.83     0.93     0.99    0.93        0.98

MGO        0.27     0.92     0.90    0.92        0.97

MG(OH)2    0.27     0.       0.90    0.          0.

FE2O3      0.30     0.95     0.90    0.95        0.86

FE(OH)3    0.30     0.       0.90    0.          0.

SIO2       0.90     0.98     0.97    0.98        0.76

INERTS     0.77     0.87     0.81    0.87        0.93

CA3(PO4)2  0.20     0.94     0.90    0.94        0.96

TOTAL      0.62              0.87                0.95

PROGRAM STOP AT 3250

USED     .91 UNITS
```

```
CASE 101


DAT1


116,30.0,9746.0,14.0,400.0,0.0,0.0,0.95
115,2.0,1.0,11.0,1.0,0.0,0.0,0.0


DAT2


131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.67,0.89


DAT3


161,0.20,0.025,0.90,0.77
171,0.27,0.27,0.30,0.30,0.40
181,0.94,0.94,0.94,0.94,0.94
182,0.94,0.94,0.94,0.94
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.94,0.93,0.98,0.87,0.0
202,0.95,0.0,0.0,0.92
211,0.957,0.904,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966



LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*              LIME USE AS CAO                    *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED     LIME*
              MG/L        MG/L       MG/L     FRACTION
11.0  30.00  302.7       111.9      190.8       0.63


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L   *      ADDED,LB/DAY        *
     14.0                9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *          FRACTION         *
       0.                     0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
 0.03           0.01                0.07   0.89



*                  PRIMARY INFLUENT COMPOSITION,MG/L                 *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0         22.3      30.0      10.00     13.2     1.9     0.


*                  PRIMARY EFFLUENT COMPOSITION,MG/L                 *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0         8.7      60.0       0.68      0.9     0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*

ORGANICS                          50580.
CAO                                   0.
CACO3                            105069.
MGO                                2200.
MG(OH)2                            8144.
FE2O3                                 0.
FE(OH)3                            2304.
SIO2                               3061.
ACID INSOL. INERTS                  453.
CA3(PO4)2                         11645.

TOTAL                            183456.


*PRIMARY SLUDGE COMPONENTS,LB/DAY*

ORGANICS                          52469.
CAO                                   0.
CACO3                            119060.
MGO                                6324.
MG(OH)2                            8502.
FE2O3                               797.
FE(OH)3                            2405.
SIO2                              10106.
ACID INSOL. INERTS                 1924.
CA3(PO4)2                         16288.

TOTAL                            217875.


*FIRST STAGE CAKE COMPONENTS,LB/DAY*
ORGANICS                          20987.
CAO                                   0.
CACO3                             98225.
MGO                                1708.
MG(OH)2                            2296.
FE2O3                               239.
FE(OH)3                             721.
SIO2                               9096.
ACID INSOL. INERTS                 1482.
CA3(PO4)2                          3258.

TOTAL                            138011.


*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*

ORGANICS                          31481.
CAO                                   0.
CACO3                             20836.
MGO                                4617.
MG(OH)2                            6207.
FE2O3                               558.
FE(OH)3                            1683.
SIO2                               1011.
ACID INSOL. INERTS                  443.
CA3(PO4)2                         13030.

TOTAL                             79865.


*RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*
ORGANICS                              0.
CAO                               48598.
CACO3                              4567.
MGO                                3020.
MG(OH)2                               0.
FE2O3                               739.
FE(OH)3                               0.
SIO2                               8914.
ACID INSOL. INERTS                 1289.
CA3(PO4)2                          3062.

TOTAL                             70190.
```

```
"RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"

ORGANICS                    0.
CAO                         0.
CACO3                    6876.
MGO                       263.
MG(OH)2                     0.
FE2O3                      39.
FE(OH)3                     0.
SIO2                      182.
ACID INSOL. INERTS        193.
CA3(PO4)2                 193.

TOTAL                    7747.


"RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY"

ORGANICS                    0.
CAO                     47674.
CACO3                    4494.
MGO                      2917.
MG(OH)2                     0.
FE2O3                     639.
FE(OH)3                     0.
SIO2                     6783.
ACID INSOL. INERTS       1197.
CA3(PO4)2                2930.

TOTAL                   66636.


"SECOND STAGE CAKE COMPONENTS,LB/DAY"

ORGANICS                29592.
CAO                         0.
CACO3                   19585.
MGO                      4340.
MG(OH)2                  5834.
FE2O3                     574.
FE(OH)3                  1562.
SIO2                [illegible]
ACID INSOL. INERTS  [illegible]
CA3(PO4)2               12249.

TOTAL                   75073.


"SECOND STAGE CENTRATE RECYCLE COMPONENTS,LB/DAY"

ORGANICS                 1889.
CAO                         0.
CACO3                    1250.
MGO                       277.
MG(OH)2                   372.
FE2O3                      33.
FE(OH)3                   101.
SIO2                       61.
ACID INSOL. INERTS         27.
CA3(PO4)2                 782.

TOTAL                    4792.


"INCINERATION FURNACE WASTE ASH COMPONENTS,LB/DAY"
ORGANICS                    0.
CAO                         0.
CACO3                   18214.
MGO                      9360.
MG(OH)2                     0.
FE2O3                    2001.
FE(OH)3                     0.
SIO2                      931.
ACID INSOL. INERTS        362.
CA3(PO4)2               11514.

TOTAL                   42382.
```

```
"INCINERATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"


ORGANICS                    0.
CAO                         0.
CACO3                    1371.
MGO                       667.
MG(OH)2                     0.
FE2O3                      85.
FE(OH)3                     0.
SIO2                       19.
ACID INSOL. INERTS         54.
CA3(PO4)2                 735.

TOTAL                    2932.


"CLASSIFIER REJECTS COMPONENTS,LB/DAY"


ORGANICS                    0.
CAO                       923.
CACO3                      73.
MGO                       103.
MG(OH)2                     0.
FE2O3                     101.
FE(OH)3                     0.
SIO2                     2130.
ACID INSOL. INERTS         92.
CA3(PO4)2                 132.

TOTAL                    3553.


"RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION"


           FIRST " RECALCINE "SECOND"INCINERATION"  DRY
           STAGE               STAGE
           CAKE     FURNACE    CAKE     FURNACE    CLASSIFIER

ORGANICS   0.40     0.         0.94     0.         0.

CAO        0.       0.93       0.       0.         0.98

CACO3      0.83     0.93       0.94     0.93       0.98

MGO        0.27     0.92       0.94     0.92       0.97

MG(OH)2    0.27     0.         0.94     0.         0.

FE2O3      0.30     0.95       0.94     0.95       0.86

FE(OH)3    0.30     0.         0.94     0.         0.

SIO2       0.90     0.98       0.94     0.98       0.76

INERTS     0.77     0.87       0.94     0.87       0.93

CA3(PO4)2  0.20     0.94       0.94     0.94       0.96

TOTAL      0.63                0.94                0.95

PROGRAM STOP AT 3250

USED     .90 UNITS
```

```
CASE 102

DAT1

110,30.0,9746.0,14.0,400.0,0.0,0.95
115,2.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0056,0.07,0.89

DAT3

161,0.20,0.825,0.90,0.77
171,0.27,0.27,0.30,0.30,0.40
181,0.99,0.99,0.99,0.99,0.99
182,0.99,0.99,0.99,0.99
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.94,0.93,0.98,0.87,0.0
202,0.95,0.0,0.0,0.92
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966

LIME SOLIDS PROCESSING MASS BALANCE

=   **FLOW*             LIME USE AS CAO                *
*PH = MGO**TOTAL DOSE**NEW LIME*  RECYCLED     LIME*
            MG/L       MG/L       MG/L     FRACTION
11.0  30.00  302.7      113.7      189.0       0.62

**FECL3 DOSE**WASTE BIOLOGICAL SLUDGE*
*    MG/L   =     ADDED,LB/DAY       *
    14.0              9746.0

**FURNACE BLOWDOWN**RECALCINING EFFICIENCY*
=     FRACTION     =        FRACTION       *
        0.                    0.95

**NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
= SIO2    = ACID INSOL. INERTS   = MGO   =CAO *
  0.03          0.01                0.07   0.89

*                  PRIMARY INFLUENT COMPOSITION,MG/L                      *
**SUSP.SOLIDS**MAGNESIUM**CALCIUM**PHOSPHORUS**SIO2**A.I.INERTS**IRON*
    240.0        22.3      30.0      10.00     13.2     1.9     0.

*                  PRIMARY EFFLUENT COMPOSITION,MG/L                      *
**SUSP.SOLIDS**MAGNESIUM**CALCIUM**PHOSPHORUS**SIO2**A.I.INERTS**IRON*
    26.0         8.7       60.0       0.68      0.9     0.1     0.
```

```
**FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*
 ORGANICS                          50580.
 CAO                                   0.
 CACO3                            105069.
 MGO                                2234.
 MG(OH)2                            8144.
 FE2O3                                 0.
 FE(OH)3                            2304.
 SIO2                               3075.
 ACID INSOL. INERTS                  458.
 CA3(PO4)2                         11645.

 TOTAL                            183509.

**PRIMARY SLUDGE COMPONENTS,LB/DAY*
 ORGANICS                          50885.
 CAO                                   0.
 CACO3                            117972.
 MGO                                5983.
 MG(OH)2                            8190.
 FE2O3                               736.
 FE(OH)3                            2320.
 SIO2                               9988.
 ACID INSOL. INERTS                 1865.
 CA3(PO4)2                         15474.

 TOTAL                            213414.

**FIRST STAGE CAKE COMPONENTS,LB/DAY*
 ORGANICS                          20354.
 CAO                                   0.
 CACO3                             97327.
 MGO                                1616.
 MG(OH)2                            2211.
 FE2O3                               221.
 FE(OH)3                             696.
 SIO2                               8990.
 ACID INSOL. INERTS                 1436.
 CA3(PO4)2                          3095.

 TOTAL                            135945.

**FIRST STAGE CENTRATE COMPONENTS,LB/DAY*

 ORGANICS                          30531.
 CAO                                   0.
 CACO3                             20645.
 MGO                                4368.
 MG(OH)2                            5979.
 FE2O3                               515.
 FE(OH)3                            1624.
 SIO2                                999.
 ACID INSOL. INERTS                  429.
 CA3(PO4)2                         12379.

 TOTAL                             77469.

**RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*

 ORGANICS                              0.
 CAO                               48154.
 CACO3                              4526.
 MGO                                2882.
 MG(OH)2                               0.
 FE2O3                               704.
 FE(OH)3                               0.
 SIO2                               8810.
 ACID INSOL. INERTS                 1249.
 CA3(PO4)2                          2909.

 TOTAL                             69234.
```

```
"RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"

ORGANICS                           0.
CAO                                0.
CACO3                           6813.
MGO                              251.
MG(OH)2                            0.
FE2O3                             37.
FE(OH)3                            0.
SIO2                             180.
ACID INSOL. INERTS               187.
CA3(PO4)2                        186.

TOTAL                           7653.


"RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY"

ORGANICS                           0.
CAO                            47239.
CACO3                           4453.
MGO                             2704.
MG(OH)2                            0.
FE2O3                            608.
FE(OH)3                            0.
SIO2                            6704.
ACID INSOL. INERTS              1161.
CA3(PO4)2                       2704.

TOTAL                          65733.


"SECOND STAGE CAKE COMPONENTS,LB/DAY"

ORGANICS                       30226.
CAO                                0.
CACO3                          20439.
MGO                             4324.
MG(OH)2                         5919.
FE2O3                            510.
FE(OH)3                         1608.
SIO2                             989.
ACID INSOL. INERTS               425.
CA3(PO4)2                      12256.

TOTAL                          76694.


"SECOND STAGE CENTRATE RECYCLE COMPONENTS,LB/DAY"

ORGANICS                         305.
CAO                                0.
CACO3                            206.
MGO                               44.
MG(OH)2                           60.
FE2O3                              5.
FE(OH)3                           16.
SIO2                              10.
ACID INSOL. INERTS                 4.
CA3(PO4)2                        124.

TOTAL                            775.


"INCINERATION FURNACE WASTE ASH COMPONENTS,LB/DAY"

ORGANICS                           0.
CAO                                0.
CACO3                          19008.
MGO                             9423.
MG(OH)2                            0.
FE2O3                           2012.
FE(OH)3                            0.
SIO2                             969.
ACID INSOL. INERTS               369.
CA3(PO4)2                      11520.

TOTAL                          43302.
```

```
"INCINERATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"


ORGANICS                           0.
CAO                                0.
CACO3                           1431.
MGO                              671.
MG(OH)2                            0.
FE2O3                             86.
FE(OH)3                            0.
SIO2                              20.
ACID INSOL. INERTS                55.
CA3(PO4)2                        735.

TOTAL                           2997.


"CLASSIFIER REJECTS COMPONENTS,LB/DAY"


ORGANICS                           0.
CAO                              915.
CACO3                             72.
MGO                               98.
MG(OH)2                            0.
FE2O3                             96.
FE(OH)3                            0.
SIO2                            2106.
ACID INSOL. INERTS                89.
CA3(PO4)2                        125.

TOTAL                           3508.


"RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION"


          FIRST " RECALCINE "SECOND"INCINERATION"  DRY
          STAGE              STAGE
          CAKE     FURNACE   CAKE     FURNACE     CLASSIFIER

ORGANICS   0.40     0.        0.99     0.           0.

CAO        0.       0.93      0.       0.           0.98

CACO3      0.83     0.93      0.99     0.93         0.98

MGO        0.27     0.92      0.99     0.92         0.97

MG(OH)2    0.27     0.        0.99     0.           0.

FE2O3      0.30     0.95      0.99     0.95         0.86

FE(OH)3    0.30     0.        0.99     0.           0.

SIO2       0.90     0.98      0.99     0.98         0.76

INERTS     0.77     0.87      0.99     0.87         0.93

CA3(PO4)2  0.20     0.94      0.99     0.94         0.96

TOTAL      0.64               0.99                  0.95

PROGRAM STOP AT 3250

USED      .90 UNITS
```

```
CASE 103

DAT1

110,30.0,9746.0,14.0,400.0,0.0,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.09

DAT3

161,0.89,0.99,0.99,0.95
171,0.97,0.97,0.87,0.87,0.91
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966



LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*             LIME USE AS CAO            *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
            MG/L       MG/L      MG/L    FRACTION
11.0  30.00  302.7      71.9     230.8     0.76


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *       ADDED,LB/DAY      *
     14.0              9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION     *       FRACTION       *
        0.                  0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01               0.07   0.89



*                  PRIMARY INFLUENT COMPOSITION,MG/L                  *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0          22.3      30.0       10.00      11.9     1.4     0.


*                  PRIMARY EFFLUENT COMPOSITION,MG/L                  *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0           8.7      60.0        0.68       0.9     0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*


ORGANICS                        50580.
CAO                                 0.
CACO3                          105069.
MGO                              1414.
MG(OH)2                          8144.
FE2O3                               0.
FE(OH)3                          2304.
SIO2                             2758.
ACID INSOL. INERTS                346.
CA3(PO4)2                       11645.

TOTAL                          182259.



*PRIMARY SLUDGE COMPONENTS,LB/DAY*


ORGANICS                        55582.
CAO                                 0.
CACO3                          120024.
MGO                            224681.
MG(OH)2                          8381.
FE2O3                           13343.
FE(OH)3                          2648.
SIO2                            11895.
ACID INSOL. INERTS               5890.
CA3(PO4)2                      323717.

TOTAL                          766161.



*FIRST STAGE CAKE COMPONENTS,LB/DAY*


ORGANICS                        50580.
CAO                                 0.
CACO3                          118823.
MGO                            217940.
MG(OH)2                          8130.
FE2O3                           11609.
FE(OH)3                          2304.
SIO2                            11776.
ACID INSOL. INERTS               5595.
CA3(PO4)2                      288108.

TOTAL                          714865.



*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*


ORGANICS                         5002.
CAO                                 0.
CACO3                            1200.
MGO                              6740.
MG(OH)2                           251.
FE2O3                            1735.
FE(OH)3                           344.
SIO2                              119.
ACID INSOL. INERTS                294.
CA3(PO4)2                       35609.

TOTAL                           51296.
```

```
=RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY=


ORGANICS                          0.
CAO                           58789.
CACO3                          5525.
MGO                          205637.
MG(OH)2                           0.
FE2O3                         12665.
FE(OH)3                           0.
SIO2                          11540.
ACID INSOL. INERTS             4868.
CA3(PO4)2                    270822.

TOTAL                        569846.




=RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY=


ORGANICS                          0.
CAO                               0.
CACO3                          8318.
MGO                           17881.
MG(OH)2                           0.
FE2O3                           667.
FE(OH)3                           0.
SIO2                            236.
ACID INSOL. INERTS              727.
CA3(PO4)2                     17287.

TOTAL                         45115.




=RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY=


ORGANICS                          0.
CAO                           57672.
CACO3                          5437.
MGO                          198645.
MG(OH)2                           0.
FE2O3                         10942.
FE(OH)3                           0.
SIO2                           8782.
ACID INSOL. INERTS             4522.
CA3(PO4)2                    259177.

TOTAL                        545177.



=CLASSIFIER REJECTS COMPONENTS,LB/DAY=


ORGANICS                          0.
CAO                            1117.
CACO3                            88.
MGO                            6992.
MG(OH)2                           0.
FE2O3                          1722.
FE(OH)3                           0.
SIO2                           2758.
ACID INSOL. INERTS              346.
CA3(PO4)2                     11645.

TOTAL                         24669.
```

```
=RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION=


           FIRST = RECALCINE ==SECOND==INCINERATION= DRY
           STAGE             STAGE
           CAKE    FURNACE   CAKE     FURNACE   CLASSIFIER

ORGANICS   0.91    0.        0.       0.        0.

CAO        0.      0.93      0.       0.        0.98

CACO3      0.99    0.93      0.       0.        0.98

MGO        0.97    0.92      0.       0.        0.97

MG(OH)2    0.97    0.        0.       0.        0.

FE2O3      0.87    0.95      0.       0.        0.86

FE(OH)3    0.87    0.        0.       0.        0.

SIO2       0.99    0.98      0.       0.        0.76

INERTS     0.95    0.87      0.       0.        0.93

CA3(PO4)2  0.89    0.94      0.       0.        0.96

TOTAL      0.93              0.                 0.96

PROGRAM STOP AT 3250

USED      .75 UNITS
```

```
CASE 104

DAT1

110,30.0,9746.0,14.0,400.0,0.1,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3

161,0.89,0.99,0.99,0.95
171,0.97,0.97,0.87,0.87,0.91
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*

ORGANICS                      50580.
CAO                               0.
CACO3                        105069.
MGO                            1888.
MG(OH)2                        8144.
FE2O3                             0.
FE(OH)3                        2304.
SIO2                           2941.
ACID INSOL. INERTS              411.
CA3(PO4)2                     11645.

TOTAL                        182982.


 *PRIMARY SLUDGE COMPONENTS,LB/DAY*

ORGANICS                      55582.
CAO                               0.
CACO3                        119406.
MGO                           58311.
MG(OH)2                        8381.
FE2O3                          7391.
FE(OH)3                        2648.
SIO2                           9621.
ACID INSOL. INERTS             3032.
CA3(PO4)2                    100359.

TOTAL                        364731.
```

```
LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*              LIME USE AS CAO              *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
              MG/L      MG/L      MG/L    FRACTION
11.0  30.00  302.7      96.1      206.6     0.68


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L   *     ADDED,LB/DAY      *
     14.0             9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *       FRACTION        *
       0.10                0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2    * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01              0.07   0.89




*                   PRIMARY INFLUENT COMPOSITION,MG/L                   *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0        22.3      30.0      10.00    12.7    1.7    0.


*                   PRIMARY EFFLUENT COMPOSITION,MG/L                   *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0         8.7      60.0       0.68     0.9    0.1    0.
```

```
CASE 105



DAT1


110,30.0,5746.0,14.0,400.0,0.15,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89


DAT3


161,0.89,0.99,0.99,0.95
171,0.97,0.97,0.87,0.87,0.91
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966


LIME SOLIDS PROCESSING MASS BALANCE



*   *FLOW*             LIME USE AS CAO           *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
                MG/L       MG/L     MG/L   FRACTION
11.0  30.00  302.7      108.1     194.7     0.64



*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *      ADDED,LB/DAY      *
     14.0             9746.0



*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *         FRACTION      *
       0.15                  0.95



*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01             0.07   0.89





*                  PRIMARY INFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0         22.3      30.0      10.00     13.0    1.8    0.



*                  PRIMARY EFFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0          8.7      60.0      0.68      0.9    0.1    0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*



ORGANICS                       50580.
CAO                                0.
CACO3                         105069.
MGO                             2124.
MG(OH)2                         8144.
FE2O3                              0.
FE(OH)3                         2304.
SIO2                            3032.
ACID INSOL. INERTS               443.
CA3(PO4)2                      11645.

TOTAL                         183340.




 *PRIMARY SLUDGE COMPONENTS,LB/DAY*



ORGANICS                       55582.
CAO                                0.
CACO3                         119099.
MGO                            42491.
MG(OH)2                         8381.
FE2O3                           5866.
FE(OH)3                         2648.
SIO2                            8849.
ACID INSOL. INERTS              2548.
CA3(PO4)2                      74617.

TOTAL                         320082.
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```
CASE 106

DAT1

110,30.0,9746.0,14.0,400.0,0.20,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3

161,0.89,0.99,0.99,0.95
171,0.97,0.97,0.87,0.87,0.91
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966


LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*            LIME USE AS CAO            *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
           MG/L       MG/L      MG/L    FRACTION
11.0  30.00  302.7    120.0     182.7     0.60


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*   MG/L  *      ADDED,LB/DAY        *
    14.0            9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION     *       FRACTION        *
       0.20                 0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2    * ACID INSOL. INERTS  * MGO  *CAO *
  0.03           0.01              0.07  0.89


*                PRIMARY INFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0        22.3      30.0      10.00     13.4    2.0     0.


*                PRIMARY EFFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    26.0         8.7       60.0      0.68      0.9     0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*


ORGANICS                        50580.
CAO                                 0.
CACO3                          105069.
MGO                              2358.
MG(OH)2                          8144.
FE2O3                               0.
FE(OH)3                          2304.
SIO2                             3122.
ACID INSOL. INERTS                475.
CA3(PO4)2                       11645.

TOTAL                          183697.


*PRIMARY SLUDGE COMPONENTS,LB/DAY*


ORGANICS                        55582.
CAO                                 0.
CACO3                          118794.
MGO                             33391.
MG(OH)2                          8381.
FE2O3                            4769.
FE(OH)3                          2648.
SIO2                             8227.
ACID INSOL. INERTS               2239.
CA3(PO4)2                       59385.

TOTAL                          293415.


*FIRST STAGE CAKE COMPONENTS,LB/DAY*


ORGANICS                        50580.
CAO                                 0.
CACO3                          117606.
MGO                             32389.
MG(OH)2                          8130.
FE2O3                            4149.
FE(OH)3                          2304.
SIO2                             8144.
ACID INSOL. INERTS               2127.
CA3(PO4)2                       52853.

TOTAL                          278281.


*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*


ORGANICS                         5002.
CAO                                 0.
CACO3                            1188.
MGO                              1002.
MG(OH)2                           251.
FE2O3                             620.
FE(OH)3                           344.
SIO2                               82.
ACID INSOL. INERTS                112.
CA3(PO4)2                        6532.

TOTAL                           15134.
```

```
*RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*


ORGANICS                    0.
CAO                     58187.
CACO3                    5469.
MGO                     34930.
MG(OH)2                     0.
FE2O3                    5578.
FE(OH)3                     0.
SIO2                     7982.
ACID INSOL. INERTS       1850.
CA3(PO4)2               49681.

TOTAL                  163676.
```

```
*RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY*


ORGANICS                    0.
CAO                         0.
CACO3                    8232.
MGO                      3037.
MG(OH)2                     0.
FE2O3                     294.
FE(OH)3                     0.
SIO2                      163.
ACID INSOL. INERTS        276.
CA3(PO4)2                3171.

TOTAL                   15174.
```

```
*RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY*


ORGANICS                    0.
CAO                     45665.
CACO3                    4305.
MGO                     26994.
MG(OH)2                     0.
FE2O3                    3855.
FE(OH)3                     0.
SIO2                     4859.
ACID INSOL. INERTS       1375.
CA3(PO4)2               38036.

TOTAL                  125089.
```

```
*RECALCINATION FURNACE BLOWDOWN COMPONENTS,LB/DAY*


ORGANICS                    0.
CAO                     11637.
CACO3                    1094.
MGO                      6986.
MG(OH)2                     0.
FE2O3                    1116.
FE(OH)3                     0.
SIO2                     1596.
ACID INSOL. INERTS        370.
CA3(PO4)2                9936.

TOTAL                   32735.
```

```
*CLASSIFIER REJECTS COMPONENTS,LB/DAY*


ORGANICS                    0.
CAO                     12522.
CACO3                    1164.
MGO                       950.
MG(OH)2                     0.
FE2O3                     607.
FE(OH)3                     0.
SIO2                     3122.
ACID INSOL. INERTS        475.
CA3(PO4)2               11645.

TOTAL                   38587.
```

```
*RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION*


           FIRST * RECALCINE *SECOND*INCINERATION*  DRY
           STAGE              STAGE
           CAKE     FURNACE   CAKE    FURNACE    CLASSIFIER

ORGANICS   0.91     0.        0.      0.         0.

CAO        0.       0.93      0.      0.         0.98

CACO3      0.99     0.93      0.      0.         0.98

MGO        0.97     0.92      0.      0.         0.97

MG(OH)2    0.97     0.        0.      0.         0.

FE2O3      0.87     0.95      0.      0.         0.86

FE(OH)3    0.87     0.        0.      0.         0.

SIO2       0.99     0.98      0.      0.         0.76

INERTS     0.95     0.87      0.      0.         0.93

CA3(PO4)2  0.89     0.94      0.      0.         0.96

TOTAL      0.95               0.                 0.76

PROGRAM STOP AT 3250

USED      .81 UNITS
```

```
CASE 107

DAT1

110,30.0,9746.0,14.0,400.0,0.24,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2


131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3


161,0.89,0.99,0.99,0.95
171,0.97,0.97,0.87,0.87,0.91
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966


LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*              LIME USE AS CAO              *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
             MG/L        MG/L     MG/L    FRACTION
11.0  30.00  302.7      129.5    173.2      0.57


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *     ADDED,LB/DAY      *
     14.0              9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *         FRACTION       *
       0.24                   0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03           0.01              0.07   0.89



*                    PRIMARY INFLUENT COMPOSITION,MG/L               *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0          22.3      30.0      10.00     13.7    2.1    0.


*                    PRIMARY EFFLUENT COMPOSITION,MG/L               *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    26.0           8.7      60.0       0.68      0.9    0.1    0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*


ORGANICS                    50580.
CAO                             0.
CACO3                      105069.
MGO                          2545.
MG(OH)2                      8144.
FE2O3                           0.
FE(OH)3                      2304.
SIO2                         3194.
ACID INSOL. INERTS            501.
CA3(PO4)2                   11645.

TOTAL                      183981.



 *PRIMARY SLUDGE COMPONENTS,LB/DAY*


ORGANICS                    55582.
CAO                             0.
CACO3                      118551.
MGO                         28488.
MG(OH)2                      8381.
FE2O3                        4090.
FE(OH)3                      2648.
SIO2                         7809.
ACID INSOL. INERTS           2061.
CA3(PO4)2                   51048.

TOTAL                      278658.



*FIRST STAGE CAKE COMPONENTS,LB/DAY*


ORGANICS

USED      .60 UNITS



110,30.0,9746.0,14.0,400.0,0.28,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0
NEW DAT1

READY
110,30.0,9746.0,14.0,400.0,0.28,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0
OLD CSOLIDS1
```

```
CASE 108

DAT1

110,30.0,9746.0,14.0,400.0,0.28,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0


DAT2


131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3


161,0.89,0.99,0.99,0.95
171,0.97,0.97,0.87,0.87,0.91
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966


LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*             LIME USE AS CAO            *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
            MG/L       MG/L      MG/L    FRACTION
11.0  30.00  302.7     138.9     163.8     0.54


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*   MG/L  *     ADDED,LB/DAY      *
    14.0            9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *        FRACTION       *
      0.28                  0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01              0.07  0.89




*                PRIMARY INFLUENT COMPOSITION,MG/L               *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
   240.0         22.3     30.0      10.00     14.0    2.2    0.


*                PRIMARY EFFLUENT COMPOSITION,MG/L               *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    26.0          8.7     60.0       0.68      0.9    0.1    0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*


ORGANICS                      50580.
CAO                               0.
CACO3                        105069.
MGO                            2730.
MG(OH)2                        8144.
FE2O3                             0.
FE(OH)3                        2304.
SIO2                           3266.
ACID INSOL. INERTS              526.
CA3(PO4)2                     11645.

TOTAL                        184264.



 *PRIMARY SLUDGE COMPONENTS,LB/DAY*


ORGANICS                      55582.
CAO                               0.
CACO3                        118309.
MGO                           24827.
MG(OH)2                        8381.
FE2O3                          3535.
FE(OH)3                        2648.
SIO2                           7446.
ACID INSOL. INERTS             1923.
CA3(PO4)2                     44764.

TOTAL                        267415.
```

```
CASE 109

DAT1

110,30.0,9746.0,14.0,400.0,0.31,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3

161,0.89,0.99,0.99,0.95
171,0.97,0.97,0.87,0.87,0.91
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966
```

```
LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*            LIME USE AS CAO            *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
           MG/L      MG/L      MG/L    FRACTION
11.0  30.00  302.7    146.0     156.7     0.52


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*   MG/L  *     ADDED,LB/DAY       *
    14.0             9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*   FRACTION    *        FRACTION       *
      0.31                 0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01             0.07  0.89



*                  PRIMARY INFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0         22.3     30.0      10.00     14.2    2.2    0.


*                  PRIMARY EFFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0          8.7     60.0       0.68      0.9    0.1    0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*


ORGANICS                    50580.
CAO                             0.
CACO3                      105069.
MGO                          2869.
MG(OH)2                      8144.
FE2O3                           0.
FE(OH)3                      2304.
SIO2                         3320.
ACID INSOL. INERTS            545.
CA3(PO4)2                   11645.

TOTAL                      184476.



*PRIMARY SLUDGE COMPONENTS,LB/DAY*


ORGANICS                    55582.
CAO                             0.
CACO3                      118129.
MGO                         22636.
MG(OH)2                      8381.
FE2O3                        3181.
FE(OH)3                      2648.
SIO2                         7205.
ACID INSOL. INERTS           1838.
CA3(PO4)2                   40980.

TOTAL                      260579.
```

```
CASE 110

DAT1

110,30.0,9746.0,14.0,400.0,0.35,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89


DAT3

161,0.89,0.99,0.99,0.95
171,0.97,0.97,0.87,0.87,0.91
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966


LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*          LIME USE AS CAO                 *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
             MG/L      MG/L     MG/L    FRACTION
11.0  30.00  302.7     155.4    147.3     0.49


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*   MG/L  *     ADDED,LB/DAY      *
    14.0            9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*   FRACTION    *        FRACTION       *
      0.35                 0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03           0.01            0.07  0.89



*                  PRIMARY INFLUENT COMPOSITION,MG/L                  *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
   240.0        22.3     30.0     10.00    14.5    2.3    0.


*                  PRIMARY EFFLUENT COMPOSITION,MG/L                  *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
   26.0         8.7      60.0      0.68     0.9    0.1    0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*

ORGANICS                     50580.
CAO                              0.
CACO3                       105069.
MGO                           3054.
MG(OH)2                       8144.
FE2O3                            0.
FE(OH)3                       2304.
SIO2                          3391.
ACID INSOL. INERTS             571.
CA3(PO4)2                    11645.

TOTAL                       184756.


 *PRIMARY SLUDGE COMPONENTS,LB/DAY*

ORGANICS                     55582.
CAO                              0.
CACO3                       117889.
MGO                          20244.
MG(OH)2                       8381.
FE2O3                         2774.
FE(OH)3                       2648.
SIO2                          6916.
ACID INSOL. INERTS            1743.
CA3(PO4)2                    36830.

TOTAL                       253006.
```

```
CASE 111

DAT1

110,30.0,9746.0,14.0,400.0,0.45,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3

161,0.89,0.99,0.99,0.95
171,0.97,0.97,0.87,0.87,0.91
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966
```

```
LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*            LIME USE AS CAO            *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
              MG/L      MG/L     MG/L    FRACTION
11.0  30.00  302.7     178.7     124.0      0.41


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *     ADDED,LB/DAY      *
     14.0             9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *        FRACTION      *
       0.45                  0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01              0.07  0.89



*                 PRIMARY INFLUENT COMPOSITION,MG/L                 *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0        22.3      30.0      10.00     15.2     2.6     0.


*                 PRIMARY EFFLUENT COMPOSITION,MG/L                 *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0         8.7      60.0       0.68      0.9  ·  0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*


ORGANICS                    50580.
CAO                             0.
CACO3                      105069.
MGO                          3512.
MG(OH)2                      8144.
FE2O3                           0.
FE(OH)3                      2304.
SIO2                         3567.
ACID INSOL. INERTS            633.
CA3(PO4)2                   11645.

TOTAL                      185454.



*PRIMARY SLUDGE COMPONENTS,LB/DAY*


ORGANICS                    55582.
CAO                             0.
CACO3                      117292.
MGO                         15981.
MG(OH)2                      8381.
FE2O3                        1991.
FE(OH)3                      2648.
SIO2                         6324.
ACID INSOL. INERTS           1567.
CA3(PO4)2                   29388.

TOTAL                      239155.



*FIRST STAGE CAKE COMPONENTS,LB/DAY*


ORGANICS                    50580.
CAO                             0.
CACO3                      116120.
MGO                         15502.
MG(OH)2                      8130.
FE2O3                        1732.
FE(OH)3                      2304.
SIO2                         6260.
ACID INSOL. INERTS           1489.
CA3(PO4)2                   26156.

TOTAL                      228271.



*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*


ORGANICS                     5002.
CAO                             0.
CACO3                        1173.
MGO                           479.
MG(OH)2                       251.
FE2O3                         259.
FE(OH)3                       344.
SIO2                           63.
ACID INSOL. INERTS             78.
CA3(PO4)2                    3233.

TOTAL                       10884.
```

```
"RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY"


                                   0.
ORGANICS                       57451.
CAO                             5400.
CACO3                          19393.
MGO                                0.
MG(OH)2                         3282.
FE2O3                              0.
FE(OH)3                         6135.
SIO2                            1295.
ACID INSOL. INERTS             24586.
CA3(PO4)2
                              117543.
TOTAL
```

```
"RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"


                                   0.
ORGANICS                           0.
CAO                             8128.
CACO3                           1686.
MGO                                0.
MG(OH)2                          173.
FE2O3                              0.
FE(OH)3                          125.
SIO2                             194.
ACID INSOL. INERTS              1569.
CA3(PO4)2
                               11876.
TOTAL
```

```
"RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY"


                                   0.
ORGANICS                       30998.
CAO                             2922.
CACO3                          10304.
MGO                                0.
MG(OH)2                         1560.
FE2O3                              0.
FE(OH)3                         2568.
SIO2                             662.
ACID INSOL. INERTS             12941.
CA3(PO4)2
                               61954.
TOTAL
```

```
"RECALCINATION FURNACE BLOWDOWN COMPONENTS,LB/DAY"


                                   0.
ORGANICS                       25853.
CAO                             2430.
CACO3                           8727.
MGO                                0.
MG(OH)2                         1477.
FE2O3                              0.
FE(OH)3                         2761.
SIO2                             583.
ACID INSOL. INERTS             11064.
CA3(PO4)2
                               52894.
TOTAL
```

```
"CLASSIFIER REJECTS COMPONENTS,LB/DAY"

                                   0.
ORGANICS                       26453.
CAO                             2477.
CACO3                            363.
MGO                                0.
MG(OH)2                          245.
FE2O3                              0.
FE(OH)3                         3567.
SIO2                             633.
ACID INSOL. INERTS             11645.
CA3(PO4)2
                               55589.
TOTAL
```

```
"RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION"

          FIRST " RECALCINE "SECOND"INCINERATION"  DRY
          STAGE             STAGE
          CAKE    FURNACE   CAKE    FURNACE   CLASSIFIER
                                                 0.
ORGANICS  0.91     0.        0.      0.          0.98
CAO       0.       0.93      0.      0.          0.98
CACO3     0.99     0.93      0.      0.          0.97
MGO       0.97     0.92      0.      0.          0.
MG(OH)2   0.97     0.        0.      0.          0.86
FE2O3     0.87     0.95      0.      0.          0.
FE(OH)3   0.87     0.        0.      0.          0.76
SIO2      0.99     0.98      0.      0.          0.93
INERTS    0.95     0.87      0.      0.          0.96
CA3(PO4)2 0.89     0.94      0.      0.          0.53
TOTAL     0.95               0.

PROGRAM STOP AT 3250

USED      .82 UNITS
```

```
CASE 112

DAT1

110,30.0,9746.0,14.0,400.0,1.0,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0


DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89


DAT3

161,0.89,0.99,0.99,0.95
171,0.97,0.97,0.87,0.87,0.91
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966


LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*             LIME USE AS CAO            *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
             MG/L      MG/L     MG/L   FRACTION
11.0  30.00  302.7     302.7      0.       0.


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *      ADDED,LB/DAY      *
     14.0            9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*     FRACTION    *        FRACTION      *
        1.00                  0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01              0.07   0.89



*              PRIMARY INFLUENT COMPOSITION,MG/L                 *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0          22.3     30.0      10.00     18.9    3.9     0.


*              PRIMARY EFFLUENT COMPOSITION,MG/L                 *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0          8.7      60.0      0.68      0.9     0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*


ORGANICS                       50580.
CAO                                0.
CACO3                         105069.
MGO                             5950.
MG(OH)2                         8144.
FE2O3                              0.
FE(OH)3                         2304.
SIO2                            4508.
ACID INSOL. INERTS               968.
CA3(PO4)2                      11645.

TOTAL                         189167.



 *PRIMARY SLUDGE COMPONENTS,LB/DAY*


ORGANICS                       55582.
CAO                                0.
CACO3                         114118.
MGO                             7167.
MG(OH)2                         8381.
FE2O3                            104.
FE(OH)3                         2648.
SIO2                            4646.
ACID INSOL. INERTS              1171.
CA3(PO4)2                      13920.

TOTAL                         207738.



*FIRST STAGE CAKE COMPONENTS,LB/DAY*


ORGANICS                       50580.
CAO                                0.
CACO3                         112977.
MGO                             6952.
MG(OH)2                         8130.
FE2O3                             91.
FE(OH)3                         2304.
SIO2                            4600.
ACID INSOL. INERTS              1112.
CA3(PO4)2                      12389.

TOTAL                         199134.



*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*


ORGANICS                        5002.
CAO                                0.
CACO3                           1141.
MGO                              215.
MG(OH)2                          251.
FE2O3                             14.
FE(OH)3                          344.
SIO2                              46.
ACID INSOL. INERTS                59.
CA3(PO4)2                       1531.

TOTAL                           8604.
```

```
"RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY"


ORGANICS                        0.
CAO                         55897.
CACO3                        5253.
MGO                         11528.
MG(OH)2                         0.
FE2O3                        1722.
FE(OH)3                         0.
SIO2                         4508.
ACID INSOL. INERTS            968.
CA3(PO4)2                   11645.

TOTAL                       91521.
```

```
"RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"


ORGANICS                        0.
CAO                             0.
CACO3                        7908.
MGO                          1002.
MG(OH)2                         0.
FE2O3                          91.
FE(OH)3                         0.
SIO2                           92.
ACID INSOL. INERTS            145.
CA3(PO4)2                     743.

TOTAL                        9981.
```

```
"RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY"


ORGANICS                        0.
CAO                             0.
CACO3                           0.
MGO                             0.
MG(OH)2                         0.
FE2O3                           0.
FE(OH)3                         0.
SIO2                            0.
ACID INSOL. INERTS              0.
CA3(PO4)2                       0.

TOTAL                           0.
```

```
"RECALCINATION FURNACE BLOWDOWN COMPONENTS,LB/DAY"


ORGANICS                        0.
CAO                         55897.
CACO3                        5253.
MGO                         11528.
MG(OH)2                         0.
FE2O3                        1722.
FE(OH)3                         0.
SIO2                         4508.
ACID INSOL. INERTS            968.
CA3(PO4)2                   11645.

TOTAL                       91521.
```

```
"CLASSIFIER REJECTS COMPONENTS,LB/DAY"


ORGANICS                        0.
CAO                             0.
CACO3                           0.
MGO                             0.
MG(OH)2                         0.
FE2O3                           0.
FE(OH)3                         0.
SIO2                            0.
ACID INSOL. INERTS              0.
CA3(PO4)2                       0.

TOTAL                           0.
```

```
"RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION"


            FIRST " RECALCINE "SECOND"INCINERATION" DRY
            STAGE              STAGE
            CAKE     FURNACE   CAKE    FURNACE    CLASSIFIER
ORGANICS    0.91     0.        0.      0.         0.

CAO         0.       0.93      0.      0.         0.98

CACO3       0.99     0.93      0.      0.         0.98

MGO         0.97     0.92      0.      0.         0.97

MG(OH)2     0.97     0.        0.      0.         0.

FE2O3       0.87     0.95      0.      0.         0.86

FE(OH)3     0.87     0.        0.      0.         0.

SIO2        0.99     0.98      0.      0.         0.76

INERTS      0.95     0.87      0.      0.         0.93

CA3(PO4)2   0.89     0.94      0.      0.         0.96

TOTAL       0.96               0.                 07E+39

PROGRAM STOP AT 5050

USED     .81 UNITS
```

```
CASE 113

DAT1

110,30.0,9746.0,14.0,400.0,0.0,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3

161,0.95,0.95,0.95,0.95
171,0.95,0.95,0.95,0.95,0.95
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966


LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*               LIME USE AS CAO           *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
             MG/L      MG/L     MG/L    FRACTION
11.0  30.00  302.7      71.9     230.8     0.76


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *     ADDED,LB/DAY      *
     14.0             9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *        FRACTION       *
       0.                   0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2    * ACID INSOL. INERTS  * MGO  *CAO *
  0.03             0.01            0.07   0.89



*                   PRIMARY INFLUENT COMPOSITION,MG/L                 *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0          22.3      30.0       10.00      11.9    1.4     0.


*                   PRIMARY EFFLUENT COMPOSITION,MG/L                 *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0          8.7       60.0       0.68       0.9     0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*


ORGANICS                      50580.
CAO                               0.
CACO3                        105069.
MGO                            1414.
MG(OH)2                        8144.
FE2O3                             0.
FE(OH)3                        2304.
SIO2                           2758.
ACID INSOL. INERTS              346.
CA3(PO4)2                     11645.

TOTAL                        182259.


*PRIMARY SLUDGE COMPONENTS,LB/DAY*


ORGANICS                      53242.
CAO                               0.
CACO3                        125077.
MGO                          229411.
MG(OH)2                        8558.
FE2O3                         12220.
FE(OH)3                        2425.
SIO2                          12396.
ACID INSOL. INERTS             5890.
CA3(PO4)2                    303272.

TOTAL                        752489.


*FIRST STAGE CAKE COMPONENTS,LB/DAY*


ORGANICS                      50580.
CAO                               0.
CACO3                        118823.
MGO                          217940.
MG(OH)2                        8130.
FE2O3                         11609.
FE(OH)3                        2304.
SIO2                          11776.
ACID INSOL. INERTS             5595.
CA3(PO4)2                    288108.

TOTAL                        714865.


*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*


ORGANICS                       2662.
CAO                               0.
CACO3                          6254.
MGO                           11471.
MG(OH)2                         428.
FE2O3                           611.
FE(OH)3                         121.
SIO2                            620.
ACID INSOL. INERTS              294.
CA3(PO4)2                     15164.

TOTAL                         37624.
```

```
*RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*


ORGANICS                        0.
CAO                         58789.
CACO3                        5525.
MGO                        205637.
MG(OH)2                         0.
FE2O3                       12665.
FE(OH)3                         0.
SIO2                        11540.
ACID INSOL. INERTS           4868.
CA3(PO4)2                  270822.

TOTAL                      569846.




*RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY*


ORGANICS                        0.
CAO                             0.
CACO3                        8318.
MGO                         17881.
MG(OH)2                         0.
FE2O3                         667.
FE(OH)3                         0.
SIO2                          236.
ACID INSOL. INERTS            727.
CA3(PO4)2                   17287.

TOTAL                       45115.




*RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY*


ORGANICS                        0.
CAO                         57672.
CACO3                        5437.
MGO                        198645.
MG(OH)2                         0.
FE2O3                       10942.
FE(OH)3                         0.
SIO2                         8782.
ACID INSOL. INERTS           4522.
CA3(PO4)2                  259177.

TOTAL                      545177.




*CLASSIFIER REJECTS COMPONENTS,LB/DAY*


ORGANICS                        0.
CAO                          1117.
CACO3                          88.
MGO                          6992.
MG(OH)2                         0.
FE2O3                        1722.
FE(OH)3                         0.
SIO2                         2758.
ACID INSOL. INERTS            346.
CA3(PO4)2                   11645.

TOTAL                       24669.
```

```
*RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION*


           FIRST * RECALCINE *SECOND*INCINERATION*  DRY
           STAGE              STAGE
           CAKE     FURNACE   CAKE     FURNACE    CLASSIFIER

ORGANICS   0.95     0.        0.       0.         0.

CAO        0.       0.93      0.       0.         0.98

CACO3      0.95     0.93      0.       0.         0.98

MGO        0.95     0.92      0.       0.         0.97

MG(OH)2    0.95     0.        0.       0.         0.

FE2O3      0.95     0.95      0.       0.         0.86

FE(OH)3    0.95     0.        0.       0.         0.

SIO2       0.95     0.98      0.       0.         0.76

INERTS     0.95     0.87      0.       0.         0.93

CA3(PO4)2  0.95     0.94      0.       0.         0.96

TOTAL      0.95               0.                  0.96

PROGRAM STOP AT 3250

USED     .80 UNITS
```

```
CASE 114

DAT1

110,30.0,9746.0,14.0,400.0,0.20,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3

161,0.95,0.95,0.95,0.95
171,0.95,0.95,0.95,0.95,0.95
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966


LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*            LIME USE AS CAO              *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
             MG/L       MG/L     MG/L   FRACTION
11.0  30.00  302.7      120.0     182.7     0.60


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *      ADDED,LB/DAY       *
     14.0              9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *        FRACTION      *
      0.20                  0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2    * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01              0.07   0.89



*                  PRIMARY INFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0          22.3      30.0       10.00      13.4     2.0     0.


*                  PRIMARY EFFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0          8.7       60.0        0.68       0.9      0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*


ORGANICS                        50580.
CAO                                 0.
CACO3                          105069.
MGO                              2358.
MG(OH)2                          8144.
FE2O3                               0.
FE(OH)3                          2304.
SIO2                             3122.
ACID INSOL. INERTS                475.
CA3(PO4)2                       11645.

TOTAL                          183697.



*PRIMARY SLUDGE COMPONENTS,LB/DAY*


ORGANICS                        53242.
CAO                                 0.
CACO3                          123796.
MGO                             34094.
MG(OH)2                          8558.
FE2O3                            4367.
FE(OH)3                          2425.
SIO2                             8573.
ACID INSOL. INERTS               2239.
CA3(PO4)2                       55634.

TOTAL                          292928.



*FIRST STAGE CAKE COMPONENTS,LB/DAY*


ORGANICS                        50580.
CAO                                 0.
CACO3                          117606.
MGO                             32389.
MG(OH)2                          8130.
FE2O3                            4149.
FE(OH)3                          2304.
SIO2                             8144.
ACID INSOL. INERTS               2127.
CA3(PO4)2                       52853.

TOTAL                          278281.



*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*


ORGANICS                         2662.
CAO                                 0.
CACO3                            6190.
MGO                              1705.
MG(OH)2                           428.
FE2O3                             218.
FE(OH)3                           121.
SIO2                              429.
ACID INSOL. INERTS                112.
CA3(PO4)2                        2782.

TOTAL                           14646.
```

```
*RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*

ORGANICS                       0.
CAO                        58187.
CACO3                       5469.
MGO                        34930.
MG(OH)2                        0.
FE2O3                       5578.
FE(OH)3                        0.
SIO2                        7982.
ACID INSOL. INERTS          1850.
CA3(PO4)2                  49681.

TOTAL                     163676.
```

```
*CLASSIFIER REJECTS COMPONENTS,LB/DAY*

ORGANICS                       0.
CAO                        12522.
CACO3                       1164.
MGO                          950.
MG(OH)2                        0.
FE2O3                        607.
FE(OH)3                        0.
SIO2                        3122.
ACID INSOL. INERTS           475.
CA3(PO4)2                  11645.

TOTAL                      38587.
```

```
*RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY*

ORGANICS                       0.
CAO                            0.
CACO3                       8232.
MGO                         3037.
MG(OH)2                        0.
FE2O3                        294.
FE(OH)3                        0.
SIO2                         163.
ACID INSOL. INERTS           276.
CA3(PO4)2                   3171.

TOTAL                      15174.
```

```
*RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY*

ORGANICS                       0.
CAO                        45665.
CACO3                       4305.
MGO                        26994.
MG(OH)2                        0.
FE2O3                       3855.
FE(OH)3                        0.
SIO2                        4859.
ACID INSOL. INERTS          1375.
CA3(PO4)2                  38036.

TOTAL                     125089.
```

```
*RECALCINATION FURNACE BLOWDOWN COMPONENTS,LB/DAY*

ORGANICS                       0.
CAO                        11637.
CACO3                       1094.
MGO                         6986.
MG(OH)2                        0.
FE2O3                       1116.
FE(OH)3                        0.
SIO2                        1596.
ACID INSOL. INERTS           370.
CA3(PO4)2                   9936.

TOTAL                      32735.
```

```
*RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION*

           FIRST * RECALCINE *SECOND*INCINERATION*  DRY
           STAGE              STAGE
           CAKE     FURNACE   CAKE    FURNACE    CLASSIFIER

ORGANICS   0.95     0.        0.      0.         0.

CAO        0.       0.93      0.      0.         0.98

CACO3      0.95     0.93      0.      0.         0.98

MGO        0.95     0.92      0.      0.         0.97

MG(OH)2    0.95     0.        0.      0.         0.

FE2O3      0.95     0.95      0.      0.         0.86

FE(OH)3    0.95     0.        0.      0.         0.

SIO2       0.95     0.98      0.      0.         0.76

INERTS     0.95     0.87      0.      0.         0.93

CA3(PO4)2  0.95     0.94      0.      0.         0.96

TOTAL      0.95               0.                 0.76

PROGRAM STOP AT 3250

USED     .81 UNITS
```

```
CASE 115

DAT1

110,30.0,9746.0,14.0,400.0,0.0,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3

161,0.995,0.995,0.995,0.995
171,0.995,0.995,0.995,0.995,0.995
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966


LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*              LIME USE AS CAO              *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
           MG/L       MG/L      MG/L     FRACTION
11.0  30.00  302.7      71.9      230.8      0.76


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *      ADDED,LB/DAY       *
     14.0               9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION     *        FRACTION       *
       0.                    0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01               0.07   0.89



*                PRIMARY INFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0        22.3      30.0      10.00     11.9    1.4     0.


*                PRIMARY EFFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    26.0         8.7       60.0      0.68      0.9     0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*


ORGANICS                       50580.
CAO                                0.
CACO3                         105069.
MGO                             1414.
MG(OH)2                         8144.
FE2O3                              0.
FE(OH)3                         2304.
SIO2                            2758.
ACID INSOL. INERTS               346.
CA3(PO4)2                      11645.

TOTAL                         182259.



*PRIMARY SLUDGE COMPONENTS,LB/DAY*


ORGANICS                       50834.
CAO                                0.
CACO3                         119421.
MGO                           219035.
MG(OH)2                         8171.
FE2O3                          11667.
FE(OH)3                         2315.
SIO2                           11835.
ACID INSOL. INERTS              5623.
CA3(PO4)2                     289556.

TOTAL                         718457.



*FIRST STAGE CAKE COMPONENTS,LB/DAY*


ORGANICS                       50580.
CAO                                0.
CACO3                         118823.
MGO                           217940.
MG(OH)2                         8130.
FE2O3                          11609.
FE(OH)3                         2304.
SIO2                           11776.
ACID INSOL. INERTS              5595.
CA3(PO4)2                     288108.

TOTAL                         714865.



*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*


ORGANICS                         254.
CAO                                0.
CACO3                            597.
MGO                             1095.
MG(OH)2                           41.
FE2O3                             58.
FE(OH)3                           12.
SIO2                              59.
ACID INSOL. INERTS                28.
CA3(PO4)2                       1448.

TOTAL                           3592.
```

```
*RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*


ORGANICS                          0.
CAO                           58789.
CACO3                          5525.
MGO                          205637.
MG(OH)2                           0.
FE2O3                         12665.
FE(OH)3                           0.
SIO2                          11540.
ACID INSOL. INERTS             4868.
CA3(PO4)2                    270822.

TOTAL                        569845.
```

```
*RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY*


ORGANICS                          0.
CAO                               0.
CACO3                          8318.
MGO                           17881.
MG(OH)2                           0.
FE2O3                           667.
FE(OH)3                           0.
SIO2                            236.
ACID INSOL. INERTS              727.
CA3(PO4)2                     17287.

TOTAL                         45115.
```

```
*RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY*


ORGANICS                          0.
CAO                           57672.
CACO3                          5437.
MGO                          193645.
MG(OH)2                           0.
FE2O3                         10942.
FE(OH)3                           0.
SIO2                           8782.
ACID INSOL. INERTS             4522.
CA3(PO4)2                    259177.

TOTAL                        545177.
```

```
*CLASSIFIER REJECTS COMPONENTS,LB/DAY*


ORGANICS                          0.
CAO                            1117.
CACO3                            88.
MGO                            6992.
MG(OH)2                           0.
FE2O3                          1722.
FE(OH)3                           0.
SIO2                           2758.
ACID INSOL. INERTS              346.
CA3(PO4)2                     11645.

TOTAL                         24668.
```

```
*RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION*


           FIRST * RECALCINE *SECOND*INCINERATION*  DRY
           STAGE             STAGE
           CAKE    FURNACE   CAKE    FURNACE     CLASSIFIER

ORGANICS   0.99    0.        0.      0.          0.

CAO        0.      0.93      0.      0.          0.98

CACO3      0.99    0.93      0.      0.          0.98

MGO        0.99    0.92      0.      0.          0.97

MG(OH)2    0.99    0.        0.      0.          0.

FE2O3      0.99    0.95      0.      0.          0.86

FE(OH)3    0.99    0.        0.      0.          0.

SIO2       0.99    0.98      0.      0.          0.76

INERTS     0.99    0.87      0.      0.          0.93

CA3(PO4)2  0.99    0.94      0.      0.          0.96

TOTAL      0.99              0.                  0.96

PROGRAM STOP AT 3250

USED     .80 UNITS
```

```
CASE 116

DAT1

110,30.0,9746.0,14.0,400.0,0.20,0.95
115,1.0,1.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3

161,0.995,0.995,0.995,0.995
171,0.995,0.995,0.995,0.995,0.995
181,0.0,0.0,0.0,0.0,0.0
182,0.0,0.0,0.0,0.0
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.0,0.0,0.0,0.0,0.0
202,0.0,0.0,0.0,0.0
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966

LIME SOLIDS PROCESSING MASS BALANCE

*   *FLOW*              LIME USE AS CAO               *
**PH * MGD**TOTAL DOSE**NEW LIME*  RECYCLED    LIME*
            MG/L      MG/L      MG/L    FRACTION
11.0  30.00  302.7     120.0     182.7     0.60

**FECL3 DOSE**WASTE BIOLOGICAL SLUDGE*
*    MG/L  *      ADDED,LB/DAY       *
     14.0              9746.0

**FURNACE BLOWDOWN**RECALCINING EFFICIENCY*
*     FRACTION     *        FRACTION       *
        0.20                    0.95

**NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2    * ACID INSOL. INERTS  * MGO  *CAO *
  0.03           0.01              0.07   0.89



*                      PRIMARY INFLUENT COMPOSITION,MG/L                    *
*SUSP.SOLIDS**MAGNESIUM**CALCIUM**PHOSPHORUS**SIO2**A.I.INERTS**IRON*
    240.0          22.3       30.0        10.00      13.4      2.0     0.

*                      PRIMARY EFFLUENT COMPOSITION,MG/L                    *
*SUSP.SOLIDS**MAGNESIUM**CALCIUM**PHOSPHORUS**SIO2**A.I.INERTS**IRON*
     26.0          8.7        60.0        0.68       0.9      0.1      0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*

ORGANICS                          50590.
CAO                                   0.
CACO3                            105069.
MGO                                2358.
MG(OH)2                            8144.
FE2O3                                 0.
FE(OH)3                            2304.
SIO2                               3122.
ACID INSOL. INERTS                  475.
CA3(PO4)2                         11645.

TOTAL                            183697.


*PRIMARY SLUDGE COMPONENTS,LB/DAY*

ORGANICS                          50834.
CAO                                   0.
CACO3                            118197.
MGO                               32552.
MG(OH)2                            8171.
FE2O3                              4170.
FE(OH)3                            2315.
SIO2                               8185.
ACID INSOL. INERTS                 2137.
CA3(PO4)2                         53118.

TOTAL                            279680.


*FIRST STAGE CAKE COMPONENTS,LB/DAY*

ORGANICS                          50580.
CAO                                   0.
CACO3                            117606.
MGO                               32389.
MG(OH)2                            8130.
FE2O3                              4149.
FE(OH)3                            2304.
SIO2                               8144.
ACID INSOL. INERTS                 2127.
CA3(PO4)2                         52853.

TOTAL                            278281.


*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*

ORGANICS                            254.
CAO                                   0.
CACO3                               591.
MGO                                 163.
MG(OH)2                              41.
FE2O3                                21.
FE(OH)3                              12.
SIO2                                 41.
ACID INSOL. INERTS                   11.
CA3(PO4)2                           266.

TOTAL                              1398.
```

```
"RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*

ORGANICS                      0.
CAO                       58187.
CACO3                      5469.
MGO                       34930.
MG(OH)2                       0.
FE2O3                      5578.
FE(OH)3                       0.
SIO2                       7982.
ACID INSOL. INERTS         1850.
CA3(PO4)2                 49681.

TOTAL                    163676.
```

```
"RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY*

ORGANICS                      0.
CAO                           0.
CACO3                      8232.
MGO                        3037.
MG(OH)2                       0.
FE2O3                       294.
FE(OH)3                       0.
SIO2                        163.
ACID INSOL. INERTS          276.
CA3(PO4)2                  3171.

TOTAL                     15174.
```

```
"RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY*

ORGANICS                      0.
CAO                       45665.
CACO3                      4305.
MGO                       26994.
MG(OH)2                       0.
FE2O3                      3855.
FE(OH)3                       0.
SIO2                       4859.
ACID INSOL. INERTS         1375.
CA3(PO4)2                 38036.

TOTAL                    125089.
```

```
"RECALCINATION FURNACE BLOWDOWN COMPONENTS,LB/DAY*

ORGANICS                      0. .
CAO                       11637.
CACO3                      1094.
MGO                        6986.
MG(OH)2                       0.
FE2O3                      1116.
FE(OH)3                       0.
SIO2                       1596.
ACID INSOL. INERTS          370.
CA3(PO4)2                  9936.

TOTAL                     32735.
```

```
"CLASSIFIER REJECTS COMPONENTS,LB/DAY*
ORGANICS                      0.
CAO                       12522.
CACO3                      1164.
MGO                         950.
MG(OH)2                       0.
FE2O3                       607.
FE(OH)3                       0.
SIO2                       3122.
ACID INSOL. INERTS          475.
CA3(PO4)2                 11645.

TOTAL                     38587.
```

```
"RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION*

            FIRST  * RECALCINE *SECOND*INCINERATION*  DRY
            STAGE              STAGE
            CAKE     FURNACE   CAKE     FURNACE     CLASSIFIER
ORGANICS    0.99     0.        0.       0.          0.
CAO         0.       0.93      0.       0.          0.98
CACO3       0.99     0.93      0.       0.          0.98
MGO         0.99     0.92      0.       0.          0.97
MG(OH)2     0.99     0.        0.       0.          0.
FE2O3       0.99     0.95      0.       0.          0.86
FE(OH)3     0.99     0.        0.       0.          0.
SIO2        0.99     0.98      0.       0.          0.76
INERTS      0.99     0.87      0.       0.          0.93
CA3(PO4)2   0.99     0.94      0.       0.          0.96
TOTAL       0.99               0.                   0.76
PROGRAM STOP AT 3250
USED     .81 UNITS
```

```
CASE 117

DAT1

110,30.0,9746.0,14.0,400.0,0.0,0.95
115,2.0,0.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3

161,0.20,0.825,0.90,0.77
171,0.27,0.27,0.30,0.30,0.40
181,0.90,0.99,0.97,0.81,0.90
182,0.90,0.78,0.90,0.90
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.94,0.93,0.98,0.87,0.0
202,0.95,0.0,0.0,0.92
211,1.0,1.0,1.0,1.0,1.0,1.0
212,1.0,1.0,1.0,1.0

LIME SOLIDS PROCESSING MASS BALANCE

*   *FLOW*                 LIME USE AS CAO             *
*PH * MGD**TOTAL DOSE**NEW LIME**  RECYCLED    LIME*
            MG/L        MG/L       MG/L    FRACTION
11.0  30.00  302.7      109.9      192.8      0.64

*FECL3 DOSE**WASTE BIOLOGICAL SLUDGE*
*    MG/L  *      ADDED,LB/DAY       *
     14.0               9746.0

*FURNACE BLOWDOWN**RECALCINING EFFICIENCY*
*    FRACTION     *         FRACTION       *
       0.                     0.95

*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2    * ACID INSOL. INERTS  * MGO  *CAO *
  0.03            0.01               0.07   0.89

*
                  PRIMARY INFLUENT COMPOSITION,MG/L              *
*SUSP.SOLIDS**MAGNESIUM**CALCIUM**PHOSPHORUS**SIO2**A.I.INERTS**IRON*
    240.0         22.3      30.0      10.00     13.1    1.9    0.

*
                  PRIMARY EFFLUENT COMPOSITION,MG/L              *
*SUSP.SOLIDS**MAGNESIUM**CALCIUM**PHOSPHORUS**SIO2**A.I.INERTS**IRON*
     26.0          8.7      60.0       0.68      0.9    0.1    0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*

ORGANICS                    50580.
CAO                             0.
CACO3                      105069.
MGO                          2160.
MG(OH)2                      8144.
FE2O3                           0.
FE(OH)3                      2304.
SIO2                         3046.
ACID INSOL. INERTS            448.
CA3(PO4)2                   11645.

TOTAL                      183395.

*PRIMARY SLUDGE COMPONENTS,LB/DAY*

ORGANICS                    58272.
CAO                             0.
CACO3                      118054.
MGO                          6784.
MG(OH)2                      8770.
FE2O3                        1026.
FE(OH)3                      2477.
SIO2                        32042.
ACID INSOL. INERTS           2764.
CA3(PO4)2                   17206.

TOTAL                      247394.

*FIRST STAGE CAKE COMPONENTS,LB/DAY*

ORGANICS                    23309.
CAO                             0.
CACO3                       97394.
MGO                          1832.
MG(OH)2                      2368.
FE2O3                         308.
FE(OH)3                       743.
SIO2                        28837.
ACID INSOL. INERTS           2128.
CA3(PO4)2                    3441.

TOTAL                      160360.

*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*

ORGANICS                    34963.
CAO                             0.
CACO3                       20659.
MGO                          4952.
MG(OH)2                      6402.
FE2O3                         718.
FE(OH)3                      1734.
SIO2                         3204.
ACID INSOL. INERTS            636.
CA3(PO4)2                   13765.

TOTAL                       87034.
```

```
"RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY"

 ORGANICS                    0.
 CAO                     48187.
 CACO3                    4529.
 MGO                      3180.
 MG(OH)2                     0.
 FE2O3                     820.
 FE(OH)3                     0.
 SIO2                    28261.
 ACID INSOL. INERTS       1851.
 CA3(PO4)2                3235.

 TOTAL                   90062.
```

```
"RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"
 ORGANICS                    0.
 CAO                         0.
 CACO3                    6818.
 MGO                       277.
 MG(OH)2                     0.
 FE2O3                      43.
 FE(OH)3                     0.
 SIO2                      577.
 ACID INSOL. INERTS        277.
 CA3(PO4)2                 206.

 TOTAL                    8197.
```

```
"RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY"

 ORGANICS                    0.
 CAO                     48187.
 CACO3                    4529.
 MGO                      3180.
 MG(OH)2                     0.
 FE2O3                     820.
 FE(OH)3                     0.
 SIO2                    28261.
 ACID INSOL. INERTS       1851.
 CA3(PO4)2                3235.

 TOTAL                   90062.
```

```
"SECOND STAGE CAKE COMPONENTS,LB/DAY"

 ORGANICS                27271.
 CAO                         0.
 CACO3                   20453.
 MGO                      4457.
 MG(OH)2                  5762.
 FE2O3                     646.
 FE(OH)3                  1561.
 SIO2                     3108.
 ACID INSOL. INERTS        515.
 CA3(PO4)2               12389.

 TOTAL                   76161.
```

```
"SECOND STAGE CENTRATE RECYCLE COMPONENTS,LB/DAY"

 ORGANICS                 7692.
 CAO                         0.
 CACO3                     207.
 MGO                       495.
 MG(OH)2                   640.
 FE2O3                      72.
 FE(OH)3                   173.
 SIO2                       96.
 ACID INSOL. INERTS        121.
 CA3(PO4)2                1377.

 TOTAL                   10873.
```

```
"INCINERATION FURNACE WASTE ASH COMPONENTS,LB/DAY"


 ORGANICS                    0.
 CAO                         0.
 CACO3                   19021.
 MGO                      9402.
 MG(OH)2                     0.
 FE2O3                    2096.
 FE(OH)3                     0.
 SIO2                     3046.
 ACID INSOL. INERTS        448.
 CA3(PO4)2               11645.

 TOTAL                   45658.
```

```
"INCINERATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"


 ORGANICS                    0.
 CAO                         0.
 CACO3                    1432.
 MGO                       673.
 MG(OH)2                     0.
 FE2O3                      91.
 FE(OH)3                     0.
 SIO2                       62.
 ACID INSOL. INERTS         67.
 CA3(PO4)2                 743.

 TOTAL                    3068.
```

```
"RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION"


           FIRST * RECALCINE "SECOND"INCINERATION"  DRY
           STAGE             STAGE
           CAKE     FURNACE  CAKE     FURNACE     CLASSIFIER

ORGANICS   0.40     0.       0.78     0.          0.

CAO        0.       0.93     0.       0.          1.00

CACO3      0.83     0.93     0.99     0.93        1.00

MGO        0.27     0.92     0.90     0.92        1.00

MG(OH)2    0.27     0.       0.90     0.          0.

FE2O3      0.30     0.95     0.90     0.95        1.00

FE(OH)3    0.30     0.       0.90     0.          0.

SIO2       0.90     0.98     0.97     0.98        1.00

INERTS     0.77     0.87     0.81     0.87        1.00

CA3(PO4)2  0.20     0.94     0.90     0.94        1.00

TOTAL      0.65              0.88                 1.00

PROGRAM STOP AT 3250

USED     .87 UNITS
```

```
CASE 118


DAT1


110,30.0,9746.0,14.0,400.0,0.20,0.95
115,2.0,0.0,11.0,1.0,0.0,0.0,0.0


DAT2


131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89


DAT3


161,0.20,0.825,0.90,0.77
171,0.27,0.27,0.30,0.30,0.40
181,0.90,0.99,0.97,0.81,0.90
182,0.90,0.78,0.90,0.90
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.94,0.93,0.98,0.87,0.0
202,0.95,0.0,0.0,0.92
211,1.0,1.0,1.0,1.0,1.0,1.0
212,1.0,1.0,1.0,1.0


LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*            LIME USE AS CAO               *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
            MG/L       MG/L      MG/L    FRACTION
11.0  30.00  302.7      149.8     152.9     0.51


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *     ADDED,LB/DAY       *
     14.0              9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *         FRACTION       *
       0.20                  0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2    * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01                0.07   0.89


*                  PRIMARY INFLUENT COMPOSITION,MG/L                  *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0          22.3     30.0      10.00     14.3    2.3     0.


*                  PRIMARY EFFLUENT COMPOSITION,MG/L                  *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0          8.7      60.0       0.68      0.9     0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*
 ORGANICS                          50580.
 CAO                                   0.
 CACO3                            105069.
 MGO                                2944.
 MG(OH)2                            8144.
 FE2O3                                 0.
 FE(OH)3                            2304.
 SIO2                               3348.
 ACID INSOL. INERTS                  555.
 CA3(PO4)2                         11645.

 TOTAL                            184589.


*PRIMARY SLUDGE COMPONENTS,LB/DAY*
 ORGANICS                          58272.
 CAO                                   0.
 CACO3                            117045.
 MGO                                7010.
 MG(OH)2                            8770.
 FE2O3                               776.
 FE(OH)3                            2477.
 SIO2                              12334.
 ACID INSOL. INERTS                 1876.
 CA3(PO4)2                         16301.

 TOTAL                            224860.


*FIRST STAGE CAKE COMPONENTS,LB/DAY*
 ORGANICS                          23309.
 CAO                                   0.
 CACO3                             96562.
 MGO                                1893.
 MG(OH)2                            2368.
 FE2O3                               233.
 FE(OH)3                             743.
 SIO2                              11101.
 ACID INSOL. INERTS                 1445.
 CA3(PO4)2                          3260.

 TOTAL                            140912.


*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*
 ORGANICS                          34963.
 CAO                                   0.
 CACO3                             20483.
 MGO                                5118.
 MG(OH)2                            6402.
 FE2O3                               543.
 FE(OH)3                            1734.
 SIO2                               1233.
 ACID INSOL. INERTS                  431.
 CA3(PO4)2                         13041.

 TOTAL                             83948.


*RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*
 ORGANICS                              0.
 CAO                               47775.
 CACO3                              4490.
 MGO                                3236.
 MG(OH)2                               0.
 FE2O3                               749.
 FE(OH)3                               0.
 SIO2                              10879.
 ACID INSOL. INERTS                 1257.
 CA3(PO4)2                          3065.

 TOTAL                             71450.
```

```
"RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"
 ORGANICS
 CAO                                 0.
 CACO3                               0.
 MGO                              6759.
 MG(OH)2                           281.
 FE2O3                               0.
 FE(OH)3                            39.
 SIO2                                0.
 ACID INSOL. INERTS                222.
 CA3(PO4)2                         188.
                                   196.
 TOTAL
                                  7686.
```

```
"RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY"

 ORGANICS                            0.
 CAO                             38220.
 CACO3                            3592.
 MGO                              2589.
 MG(OH)2                             0.
 FE2O3                             599.
 FE(OH)3                             0.
 SIO2                             8703.
 ACID INSOL. INERTS               1005.
 CA3(PO4)2                        2452.

 TOTAL                           57160.
```

```
"SECOND STAGE CAKE COMPONENTS,LB/DAY"

 ORGANICS                        27271.
 CAO                                 0.
 CACO3                           20278.
 MGO                              4606.
 MG(OH)2                          5762.
 FE2O3                             489.
 FE(OH)3                          1561.
 SIO2                             1196.
 ACID INSOL. INERTS                350.
 CA3(PO4)2                       11737.

 TOTAL                           73249.
```

```
"SECOND STAGE CENTRATE RECYCLE COMPONENTS,LB/DAY"
 ORGANICS                         7692.
 CAO                                 0.
 CACO3                             205.
 MGO                               512.
 MG(OH)2                           640.
 FE2O3                              54.
 FE(OH)3                           173.
 SIO2                               37.
 ACID INSOL. INERTS                 82.
 CA3(PO4)2                        1304.

 TOTAL                           10699.
```

```
"INCINERATION FURNACE WASTE ASH COMPONENTS,LB/DAY"
 ORGANICS                            0.
 CAO                                 0.
 CACO3                           18859.
 MGO                              9538.
 MG(OH)2                             0.
 FE2O3                            1947.
 FE(OH)3                             0.
 SIO2                             1172.
 ACID INSOL. INERTS                304.
 CA3(PO4)2                       11032.

 TOTAL                           42853.
```

```
"INCINERATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"

 ORGANICS                            0.
 CAO                                 0.
 CACO3                            1419.
 MGO                               685.
 MG(OH)2                             0.
 FE2O3                              83.
 FE(OH)3                             0.
 SIO2                               24.
 ACID INSOL. INERTS                 45.
 CA3(PO4)2                         704.

 TOTAL                            2961.
```

```
"RECALCINATION FURNACE BLOWDOWN COMPONENTS,LB/DAY"

 ORGANICS                            0.
 CAO                              9555.
 CACO3                             898.
 MGO                               647.
 MG(OH)2                             0.
 FE2O3                             150.
 FE(OH)3                             0.
 SIO2                             2176.
 ACID INSOL. INERTS                251.
 CA3(PO4)2                         613.

 TOTAL                           14290.
```

```
"RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION"

            FIRST " RECALCINE "SECOND"INCINERATION"  DRY
            STAGE              STAGE
            CAKE     FURNACE   CAKE     FURNACE   CLASSIFIER
 ORGANICS   0.40     0.        0.78     0.        0.

 CAO        0.       0.93      0.       0.        1.00

 CACO3      0.83     0.93      0.99     0.93      1.00

 MGO        0.27     0.92      0.90     0.92      1.00

 MG(OH)2    0.27     0.        0.90     0.        0.

 FE2O3      0.30     0.95      0.90     0.95      1.00

 FE(OH)3    0.30     0.        0.90     0.        0.

 SIO2       0.90     0.98      0.97     0.98      1.00

 INERTS     0.77     0.87      0.81     0.87      1.00

 CA3(PO4)2  0.20     0.94      0.90     0.94      1.00

 TOTAL      0.63               0.87               0.80

 PROGRAM STOP AT 3250

 USED      .90 UNITS
```

```
CASE 119

DAT1

110,30.0,9746.0,14.0,400.0,0.24,0.95
115,2.0,0.0,11.0,1.0,0.0,0.0,0.0

DAT2

131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3

161,0.20,0.825,0.90,0.77
171,0.27,0.27,0.30,0.30,0.40
181,0.90,0.99,0.97,0.81,0.90
182,0.90,0.78,0.90,0.90
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.94,0.93,0.98,0.87,0.0
202,0.95,0.0,0.0,0.92
211,1.0,1.0,1.0,1.0,1.0,1.0
212,1.0,1.0,1.0,1.0

LIME SOLIDS PROCESSING MASS BALANCE

*   *FLOW*              LIME USE AS CAO              *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
             MG/L       MG/L      MG/L     FRACTION
11.0  30.00  302.7      157.7     145.0      0.48

*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*   MG/L   *    ADDED,LB/DAY        *
    14.0             9746.0

*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *        FRACTION       *
       0.24                 0.95

*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01              0.07   0.89

*                    PRIMARY INFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0        22.3      30.0      10.00     14.5    2.4     0.

*                    PRIMARY EFFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    26.0         8.7       60.0      0.68      0.9     0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*
 ORGANICS                            50580.
 CAO                                     0.
 CACO3                              105069.
 MGO                                  3099.
 MG(OH)2                              8144.
 FE2O3                                   0.
 FE(OH)3                              2304.
 SIO2                                 3408.
 ACID INSOL. INERTS                    577.
 CA3(PO4)2                           11645.

 TOTAL                              184825.

*PRIMARY SLUDGE COMPONENTS,LB/DAY*
 ORGANICS                            58272.
 CAO                                     0.
 CACO3                              116845.
 MGO                                  7049.
 MG(OH)2                              8770.
 FE2O3                                 731.
 FE(OH)3                              2477.
 SIO2                                11111.
 ACID INSOL. INERTS                   1786.
 CA3(PO4)2                           16131.

 TOTAL                              223171.

*FIRST STAGE CAKE COMPONENTS,LB/DAY*
 ORGANICS                            23309.
 CAO                                     0.
 CACO3                               96397.
 MGO                                  1903.
 MG(OH)2                              2368.
 FE2O3                                 219.
 FE(OH)3                               743.
 SIO2                                10000.
 ACID INSOL. INERTS                   1375.
 CA3(PO4)2                            3226.

 TOTAL                              139540.

*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*
 ORGANICS                            34963.
 CAO                                     0.
 CACO3                               20448.
 MGO                                  5146.
 MG(OH)2                              6402.
 FE2O3                                 511.
 FE(OH)3                              1734.
 SIO2                                 1111.
 ACID INSOL. INERTS                    411.
 CA3(PO4)2                           12905.

 TOTAL                               83631.

*RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*
 ORGANICS                                0.
 CAO                                 47693.
 CACO3                                4482.
 MGO                                  3246.
 MG(OH)2                                 0.
 FE2O3                                 736.
 FE(OH)3                                 0.
 SIO2                                 9800.
 ACID INSOL. INERTS                   1197.
 CA3(PO4)2                            3033.

 TOTAL                               70186.
```

```
"RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"

ORGANICS                       0.
CAO                            0.
CACO3                       6748.
MGO                          282.
MG(OH)2                        0.
FE2O3                         39.
FE(OH)3                        0.
SIO2                         200.
ACID INSOL. INERTS           179.
CA3(PO4)2                    194.

TOTAL                       7641.
```

```
"RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY"

ORGANICS                       0.
CAO                        36247.
CACO3                       3407.
MGO                         2467.
MG(OH)2                        0.
FE2O3                        559.
FE(OH)3                        0.
SIO2                        7448.
ACID INSOL. INERTS           909.
CA3(PO4)2                   2305.

TOTAL                      53342.
```

```
"SECOND STAGE CAKE COMPONENTS,LB/DAY"

ORGANICS                   27271.
CAO                            0.
CACO3                      20243.
MGO                         4631.
MG(OH)2                     5762.
FE2O3                        460.
FE(OH)3                     1561.
SIO2                        1078.
ACID INSOL. INERTS           333.
CA3(PO4)2                  11614.

TOTAL                      72953.
```

```
"SECOND STAGE CENTRATE RECYCLE COMPONENTS,LB/DAY"

ORGANICS                    7692.
CAO                            0.
CACO3                        204.
MGO                          515.
MG(OH)2                      640.
FE2O3                         51.
FE(OH)3                      173.
SIO2                          33.
ACID INSOL. INERTS            78.
CA3(PO4)2                   1290.

TOTAL                      10678.
```

```
"INCINERATION FURNACE WASTE ASH COMPONENTS,LB/DAY"

ORGANICS                       0.
CAO                            0.
CACO3                      18826.
MGO                         9562.
MG(OH)2                        0.
FE2O3                       1920.
FE(OH)3                        0.
SIO2                        1056.
ACID INSOL. INERTS           290.
CA3(PO4)2                  10918.

TOTAL                      42571.
```

```
"INCINERATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"


ORGANICS                       0.
CAO                            0.
CACO3                       1417.
MGO                          687.
MG(OH)2                        0.
FE2O3                         81.
FE(OH)3                        0.
SIO2                          22.
ACID INSOL. INERTS            43.
CA3(PO4)2                    697.

TOTAL                       2947.
```

```
"RECALCINATION FURNACE BLOWDOWN COMPONENTS,LB/DAY"


ORGANICS                       0.
CAO                        11446.
CACO3                       1076.
MGO                          779.
MG(OH)2                        0.
FE2O3                        177.
FE(OH)3                        0.
SIO2                        2352.
ACID INSOL. INERTS           287.
CA3(PO4)2                    728.

TOTAL                      16845.
```

```
"RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION"


           FIRST " RECALCINE "SECOND"INCINERATION"  DRY
           STAGE             STAGE
           CAKE    FURNACE   CAKE    FURNACE    CLASSIFIER

ORGANICS   0.40    0.        0.78    0.         0.

CAO        0.      0.93      0.      0.         1.00

CACO3      0.83    0.93      0.99    0.93       1.00

MGO        0.27    0.92      0.90    0.92       1.00

MG(OH)2    0.27    0.        0.90    0.         0.

FE2O3      0.30    0.95      0.90    0.95       1.00

FE(OH)3    0.30    0.        0.90    0.         0.

SIO2       0.90    0.98      0.97    0.98       1.00

INERTS     0.77    0.87      0.81    0.87       1.00

CA3(PO4)2  0.20    0.94      0.90    0.94       1.00

TOTAL      0.63              0.87               1.00

PROGRAM STOP AT 5050

USED     .90 UNITS
```

```
 CASE 120


DAT1


110,30.0,9746.0,14.0,400.0,0.28,0.95
115,2.0,0.0,11.0,1.0,0.0,0.0,0.0

DAT2


131,240.0,26.0,22.3,8.74,30.0,60.0
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89


DAT3


161,0.20,0.825,0.90,0.77
171,0.27,0.27,0.30,0.30,0.40
181,0.90,0.99,0.97,0.81,0.90
182,0.90,0.78,0.90,0.90
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.94,0.93,0.98,0.87,0.0
202,0.95,0.0,0.0,0.92
211,1.0,1.0,1.0,1.0,1.0,1.0
212,1.0,1.0,1.0,1.0

LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*               LIME USE AS CAO            *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
              MG/L       MG/L      MG/L   FRACTION
11.0  30.00  302.7      165.5     137.2     0.45


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *     ADDED,LB/DAY       *
     14.0              9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION    *        FRACTION       *
       0.28                 0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03          0.01              0.07  0.89


*                   PRIMARY INFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0          22.3      30.0      10.00     14.8    2.5     0.


*                   PRIMARY EFFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    26.0            8.7      60.0      0.68       0.9     0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*
 ORGANICS                        50580.
 CAO                                 0.
 CACO3                          105069.
 MGO                              3253.
 MG(OH)2                          8144.
 FE2O3                               0.
 FE(OH)3                          2304.
 SIO2                             3468.
 ACID INSOL. INERTS                598.
 CA3(PO4)2                       11645.

 TOTAL                          185061.


*PRIMARY SLUDGE COMPONENTS,LB/DAY*
 ORGANICS                        58272.
 CAO                                 0.
 CACO3                          116646.
 MGO                              7086.
 MG(OH)2                          8770.
 FE2O3                             687.
 FE(OH)3                          2477.
 SIO2                            10139.
 ACID INSOL. INERTS               1710.
 CA3(PO4)2                       15965.

 TOTAL                          221752.


*FIRST STAGE CAKE COMPONENTS,LB/DAY*

 ORGANICS                        23309.
 CAO                                 0.
 CACO3                           96233.
 MGO                              1913.
 MG(OH)2                          2368.
 FE2O3                             206.
 FE(OH)3                           743.
 SIO2                             9125.
 ACID INSOL. INERTS               1317.
 CA3(PO4)2                        3193.

 TOTAL                          138407.


*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*
 ORGANICS                        34963.
 CAO                                 0.
 CACO3                           20413.
 MGO                              5173.
 MG(OH)2                          6402.
 FE2O3                             481.
 FE(OH)3                          1734.
 SIO2                             1014.
 ACID INSOL. INERTS                393.
 CA3(PO4)2                       12772.

 TOTAL                           83345.


*RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*

 ORGANICS                            0.
 CAO                             47612.
 CACO3                            4475.
 MGO                              3255
 MG(OH)2                             0.
 FE2O3                             724.
 FE(OH)3                             0.
 SIO2                             8943.
 ACID INSOL. INERTS               1146.
 CA3(PO4)2                        3001.

 TOTAL                           69155.
```

```
"RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"
ORGANICS                        0.
CAO                             0.
CACO3                        6736.
MGO                           283.
MG(OH)2                         0.
FE2O3                          38.
FE(OH)3                         0.
SIO2                          183.
ACID INSOL. INERTS            171.
CA3(PO4)2                     192.

TOTAL                        7603.
```

```
"RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY"
ORGANICS                        0.
CAO                         34281.
CACO3                        3222.
MGO                          2343.
MG(OH)2                         0.
FE2O3                         521.
FE(OH)3                         0.
SIO2                         6439.
ACID INSOL. INERTS            825.
CA3(PO4)2                    2161.

TOTAL                       49792.
```

```
"SECOND STAGE CAKE COMPONENTS,LB/DAY"

ORGANICS                    27271.
CAO                             0.
CACO3                       20209.
MGO                          4655.
MG(OH)2                      5762.
FE2O3                         433.
FE(OH)3                      1561.
SIO2                          983.
ACID INSOL. INERTS            319.
CA3(PO4)2                   11495.

TOTAL                       72688.
```

```
"SECOND STAGE CENTRATE RECYCLE COMPONENTS,LB/DAY"

ORGANICS                     7692.
CAO                             0.
CACO3                         204.
MGO                           517.
MG(OH)2                       640.
FE2O3                          48.
FE(OH)3                       173.
SIO2                           30.
ACID INSOL. INERTS             75.
CA3(PO4)2                    1277.

TOTAL                       10657.
```

```
"INCINERATION FURNACE WASTE ASH COMPONENTS,LB/DAY"

ORGANICS                        0.
CAO                             0.
CACO3                       18794.
MGO                          9584.
MG(OH)2                         0.
FE2O3                        1894.
FE(OH)3                         0.
SIO2                          964.
ACID INSOL. INERTS            277.
CA3(PO4)2                   10805.

TOTAL                       42318.
```

```
"INCINERATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"


ORGANICS                        0.
CAO                             0.
CACO3                        1415.
MGO                           689.
MG(OH)2                         0.
FE2O3                          80.
FE(OH)3                         0.
SIO2                           20.
ACID INSOL. INERTS             41.
CA3(PO4)2                     690.

TOTAL                        2934.
```

```
"RECALCINATION FURNACE BLOWDOWN COMPONENTS,LB/DAY"


ORGANICS                        0.
CAO                         13331.
CACO3                        1253.
MGO                           911.
MG(OH)2                         0.
FE2O3                         203.
FE(OH)3                         0.
SIO2                         2504.
ACID INSOL. INERTS            321.
CA3(PO4)2                     840.

TOTAL                       19363.
```

```
"RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION"


           FIRST " RECALCINE "SECOND""INCINERATION"  DRY
           STAGE              STAGE
           CAKE    FURNACE    CAKE     FURNACE    CLASSIFIER

ORGANICS   0.40      0.        0.78      0.          0.

CAO        0.        0.93      0.        0.          1.00

CACO3      0.83      0.93      0.99      0.93        1.00

MGO        0.27      0.92      0.90      0.92        1.00

MG(OH)2    0.27      0.        0.90      0.          0.

FE2O3      0.30      0.95      0.90      0.95        1.00

FE(OH)3    0.30      0.        0.90      0.          0.

SIO2       0.90      0.98      0.97      0.98        1.00

INERTS     0.77      0.87      0.81      0.87        1.00

CA3(PO4)2  0.20      0.94      0.90      0.94        1.00

TOTAL      0.62                0.87                  1.00

PROGRAM STOP AT 5050

USED     .89 UNITS
```

```
CASE 121

DAT1:

110,30.0,12995.0,24.0,289.0,0.0,0.95
115,2.0,1.0,10.2,1.0,0.0,0.0,0.0

DAT2


131,240.0,26.0,22.3,15.6,30.0,65.2
132,10.0,0.68,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89

DAT3


161,0.26,0.72,0.90,0.64
171,0.25,0.25,0.18,0.18,0.35
181,0.93,0.83,0.81,0.68,0.75
182,0.75,0.78,0.90,0.90
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.94,0.93,0.98,0.87,0.0
202,0.95,0.0,0.0,0.92
211,0.957,0.984,0.761,0.929,0.0,0.981
212,0.864,0.0,0.0,0.966


LIME SOLIDS PROCESSING MASS BALANCE


*   *FLOW*             LIME USE AS CAO           *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
              MG/L       MG/L      MG/L   FRACTION
10.2  30.00  218.7      113.2      105.5     0.48


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *     ADDED,LB/DAY       *
     24.0             12995.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION     *         FRACTION      *
        0.                    0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2    * ACID INSOL. INERTS   * MGO   *CAO *
  0.03           0.01               0.07   0.89



*                  PRIMARY INFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0          22.3      30.0      10.00     13.7     1.9     0.


*                  PRIMARY EFFLUENT COMPOSITION,MG/L                *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     26.0          15.6      65.2       0.68      0.9     0.1     0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*
 ORGANICS                          53179.
 CAO                                   0.
 CACO3                             64335.
 MGO                                2225.
 MG(OH)2                            4024.
 FE2O3                                 0.
 FE(OH)3                            3949.
 SIO2                               3185.
 ACID INSOL. INERTS                  465.
 CA3(PO4)2                         11645.

 TOTAL                            143007.


*PRIMARY SLUDGE COMPONENTS,LB/DAY*
 ORGANICS                          62052.
 CAO                                   0.
 CACO3                             75441.
 MGO                                4942.
 MG(OH)2                            4343.
 FE2O3                              1146.
 FE(OH)3                            4968.
 SIO2                              10975.
 ACID INSOL. INERTS                 1840.
 CA3(PO4)2                         17714.

 TOTAL                            183421.


*FIRST STAGE CAKE COMPONENTS,LB/DAY*

 ORGANICS                          21718.
 CAO                                   0.
 CACO3                             54318.
 MGO                                1235.
 MG(OH)2                            1086.
 FE2O3                               206.
 FE(OH)3                             894.
 SIO2                               9878.
 ACID INSOL. INERTS                 1178.
 CA3(PO4)2                          4606.

 TOTAL                             95119.


*FIRST STAGE CENTRATE COMPONENTS LB/DAY*

 ORGANICS                          40334.
 CAO                                   0.
 CACO3                             21123.
 MGO                                3706.
 MG(OH)2                            3257.
 FE2O3                               940.
 FE(OH)3                            4073.
 SIO2                               1098.
 ACID INSOL. INERTS                  663.
 CA3(PO4)2                         13108.

 TOTAL                             88303.

*RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*

 ORGANICS                              0.
 CAO                               26874.
 CACO3                              2526.
 MGO                                1822.
 MG(OH)2                               0.
 FE2O3                               831.
 FE(OH)3                               0.
 SIO2                               9680.
 ACID INSOL. INERTS                 1025.
 CA3(PO4)2                          4329.

 TOTAL                             47087.
```

```
"RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"

 ORGANICS                          0.
 CAO                               0.
 CACO3                          3802.
 MGO                             158.
 MG(OH)2                           0.
 FE2O3                            44.
 FE(OH)3                           0.
 SIO2                            198.
 ACID INSOL. INERTS              153.
 CA3(PO4)2                       276.

 TOTAL                          4631.
```

```
"RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY"

 ORGANICS                          0.
 CAO                           26364.
 CACO3                          2485.
 MGO                            1760.
 MG(OH)2                           0.
 FE2O3                           718.
 FE(OH)3                           0.
 SIO2                           7367.
 ACID INSOL. INERTS              952.
 CA3(PO4)2                      4143.

 TOTAL                         43789.
```

```
"SECOND STAGE CAKE COMPONENTS,LB/DAY"

 ORGANICS                      31461.
 CAO                               0.
 CACO3                         17532.
 MGO                            3336.
 MG(OH)2                        2931.
 FE2O3                           705.
 FE(OH)3                        3055.
 SIO2                            889.
 ACID INSOL. INERTS              451.
 CA3(PO4)2                     17191.

 TOTAL                         77550.
```

```
"SECOND STAGE CENTRATE RECYCLE COMPONENTS,LB/DAY"

 ORGANICS                       8873.
 CAO                               0.
 CACO3                          3591.
 MGO                             371.
 MG(OH)2                         326.
 FE2O3                           235.
 FE(OH)3                        1018.
 SIO2                            209.
 ACID INSOL. INERTS              212.
 CA3(PO4)2                       918.

 TOTAL                         15752.
```

```
"INCINERATION FURNACE WASTE ASH COMPONENTS,LB/DAY"

 ORGANICS                          0.
 CAO                               0.
 CACO3                         16305.
 MGO                            5766.
 MG(OH)2.                          0.
 FE2O3                          3572.
 FE(OH)3                           0.
 SIO2                            871.
 ACID INSOL. INERTS              392.
 CA3(PO4)2                     11459.

 TOTAL                         38365.
```

```
"INCINERATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"


ORGANICS                           0.
CAO                                0.
CACO3                           1227.
MGO                              428.
MG(OH)2                            0.
FE2O3                            149.
FE(OH)3                            0.
SIO2                              18.
ACID INSOL. INERTS                59.
CA3(PO4)2                        731.

TOTAL                           2612.
```

```
"CLASSIFIER REJECTS COMPONENTS,LB/DAY"


ORGANICS                           0.
CAO                              511.
CACO3                             40.
MGO                               62.
MG(OH)2                            0.
FE2O3                            113.
FE(OH)3                            0.
SIO2                            2314.
ACID INSOL. INERTS                73.
CA3(PO4)2                        186.

TOTAL                           3299.
```

```
"RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION"


           FIRST " RECALCINE "SECOND"INCINERATION"  DRY
           STAGE              STAGE
           CAKE    FURNACE    CAKE    FURNACE    CLASSIFIER

ORGANICS   0.35    0.         0.78    0.         0.

CAO        0.      0.93       0.      0.         0.98

CACO3      0.72    0.93       0.83    0.93       0.98

MGO        0.25    0.92       0.90    0.92       0.97

MG(OH)2    0.25    0.         0.90    0.         0.

FE2O3      0.18    0.95       0.75    0.95       0.86

FE(OH)3    0.18    0.         0.75    0.         0.

SIO2       0.90    0.98       0.81    0.98       0.76

INERTS     0.64    0.87       0.68    0.87       0.93

CA3(PO4)2  0.26    0.94       0.93    0.94       0.96

TOTAL      0.52               0.82               0.93

PROGRAM STOP AT 5050

USED       .90 UNITS
```

```
CASE 122


DAT1
110,30.0,9746.0,0.0,500.0,0.0,0.95
115,2.0,1.0,11.5,1.0,0.0,0.0,0.0


DAT2

131,240.0,35.0,22.3,9.72,28.8,72.8
132,10.0,0.96,0.0,0.0024,0.0024
141,0.035,0.0024,0.80,0.80,0.80
151,0.035,0.035,0.027,0.0096,0.07,0.89


DAT3


161,0.23,0.86,0.91,0.75
171,0.30,0.30,0.18,0.18,0.41
181,0.90,0.99,0.97,0.81,0.75
182,0.75,0.78,0.90,0.90
191,0.94,0.93,0.98,0.87,0.0
192,0.95,0.0,0.0,0.92
201,0.94,0.93,0.98,0.87,0.0
202,0.95,0.0,0.0,0.92
211,0.957,0.984,0.761,0.929,0.0,0.901
212,0.864,0.0,0.0,0.966



LIME SOLIDS PROCESSING MASS BALANCE



*   *FLOW*             LIME USE AS CAO            *
*PH * MGD*TOTAL DOSE*NEW LIME*  RECYCLED    LIME*
             MG/L       MG/L      MG/L    FRACTION
11.5  30.00  378.4      133.4     245.0     0.65


*FECL3 DOSE*WASTE BIOLOGICAL SLUDGE*
*    MG/L  *      ADDED,LB/DAY       *
     0.                9746.0


*FURNACE BLOWDOWN*RECALCINING EFFICIENCY*
*    FRACTION     *          FRACTION      *
        0.                      0.95


*NEW MAKEUP LIME ADDED,FRACTION COMPOSITION*
* SIO2   * ACID INSOL. INERTS  * MGO  *CAO *
  0.03           0.01              0.07   0.89



*                   PRIMARY INFLUENT COMPOSITION,MG/L                   *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
    240.0         22.3       28.8       10.00      13.8      2.1      0.


*                   PRIMARY EFFLUENT COMPOSITION,MG/L                   *
*SUSP.SOLIDS*MAGNESIUM*CALCIUM*PHOSPHORUS*SIO2*A.I.INERTS*IRON*
     35.0          9.7       72.8        0.96       1.2      0.1      0.
```

```
*FIRST PASS PRECIPITATION COMPONENTS,LB/DAY*

 ORGANICS                          48780.
 CAO                                   0.
 CACO3                            130431.
 MGO                                2622.
 MG(OH)2                            7555.
 FE2O3                                 0.
 FE(OH)3                               0.
 SIO2                               3146.
 ACID INSOL. INERTS                  506.
 CA3(PO4)2                         11295.

 TOTAL                            204336.



*PRIMARY SLUDGE COMPONENTS,LB/DAY*

 ORGANICS                          56057.
 CAO                                   0.
 CACO3                            146659.
 MGO                                7674.
 MG(OH)2                            8110.
 FE2O3                                 0.
 FE(OH)3                               0.
 SIO2                              10531.
 ACID INSOL. INERTS                 2274.
 CA3(PO4)2                         17096.

 TOTAL                            248401.



*FIRST STAGE CAK  COMPONENTS,LB/DAY*

 ORGANICS                          22983.
 CAO                                   0.
 CACO3                            126127.
 MGO                                2302.
 MG(OH)2                            2433.
 FE2O3                                 0.
 FE(OH)3                               0.
 SIO2                               9583.
 ACID INSOL. INERTS                 1705.
 CA3(PO4)2                          3932.

 TOTAL                            169066.


*FIRST STAGE CENTRATE COMPONENTS,LB/DAY*

 ORGANICS                          33073.
 CAO                                   0.
 CACO3                             20532.
 MGO                                5372.
 MG(OH)2                            5677.
 FE2O3                                 0.
 FE(OH)3                               0.
 SIO2                                948.
 ACID INSOL. INERTS                  568.
 CA3(PO4)2                         13164.

 TOTAL                             79334.



*RECALCINATION FURNACE PRODUCT COMPONENTS,LB/DAY*

 ORGANICS                              0.
 CAO                               62403.
 CACO3                              5865.
 MGO                                3654.
 MG(OH)2                               0.
 FE2O3                                 0.
 FE(OH)3                               0.
 SIO2                               9392.
 ACID INSOL. INERTS                 1484.
 CA3(PO4)2                          3696.

 TOTAL                             86493.
```

```
"RECALCINATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"

ORGANICS                         0.
CAO                              0.
CACO3                         8829.
MGO                            318.
MG(OH)2                          0.
FE2O3                            0.
FE(OH)3                          0.
SIO2                           192.
ACID INSOL. INERTS             222.
CA3(PO4)2                      236.

TOTAL                         9796.
```

```
"RECYCLED SOLIDS ACCEPTS COMPONENTS,LB/DAY"

ORGANICS                         0.
CAO                          61217.
CACO3                         5771.
MGO                           3530.
MG(OH)2                          0.
FE2O3                            0.
FE(OH)3                          0.
SIO2                          7147.
ACID INSOL. INERTS            1378.
CA3(PO4)2                     3537.

TOTAL                        82580.
```

```
"SECOND STAGE CAKE COMPONENTS,LB/DAY"

ORGANICS                     25797.
CAO                              0.
CACO3                        20327.
MGO                           4835.
MG(OH)2                       5109.
FE2O3                            0.
FE(OH)3                          0.
SIO2                           919.
ACID INSOL. INERTS             460.
CA3(PO4)2                    11847.

TOTAL                        69295.
```

```
"SECOND STAGE CENTRATE RECYCLE COMPONENTS,LB/DAY"

ORGANICS                      7276.
CAO                              0.
CACO3                          205.
MGO                            537.
MG(OH)2                        568.
FE2O3                            0.
FE(OH)3                          0.
SIO2                            28.
ACID INSOL. INERTS             108.
CA3(PO4)2                     1316.

TOTAL                        10039.
```

```
"INCINERATION FURNACE WASTE ASH COMPONENTS,LB/DAY"

ORGANICS                         0.
CAO                              0.
CACO3                        18904.
MGO                           9148.
MG(OH)2                          0.
FE2O3                            0.
FE(OH)3                          0.
SIO2                           901.
ACID INSOL. INERTS             401.
CA3(PO4)2                    11137.

TOTAL                        40491.
```

```
"INCINERATION FURNACE WET SCRUBBER WATER COMPONENTS,LB/DAY"


ORGANICS                         0.
CAO                              0.
CACO3                         1423.
MGO                            667.
MG(OH)2                          0.
FE2O3                            0.
FE(OH)3                          0.
SIO2                            18.
ACID INSOL. INERTS              60.
CA3(PO4)2                      711.

TOTAL                         2879.
```

```
"CLASSIFIER REJECTS COMPONENTS,LB/DAY"


ORGANICS                         0.
CAO                           1186.
CACO3                           94.
MGO                            124.
MG(OH)2                          0.
FE2O3                            0.
FE(OH)3                          0.
SIO2                          2245.
ACID INSOL. INERTS             105.
CA3(PO4)2                      159.

TOTAL                         3913.
```

```
"RECOVERIES OF COMPONENTS IN PROCESS STREAMS,FRACTION"


           FIRST " RECALCINE "SECOND"INCINERATION"  DRY
           STAGE             STAGE
           CAKE    FURNACE   CAKE    FURNACE     CLASSIFIER

ORGANICS   0.41    0.        0.78    0.          0.

CAO        0.      0.93      0.      0.          0.98

CACO3      0.86    0.93      0.99    0.93        0.98

MGO        0.30    0.92      0.90    0.92        0.97

MG(OH)2    0.30    0.        0.90    0.          0.

FE2O3      0.18    0.95      0.75    0.95        0.86

FE(OH)3    0.18    0.        0.75    0.          0.

SIO2       0.91    0.98      0.97    0.98        0.76

INERTS     0.75    0.87      0.81    0.87        0.93

CA3(PO4)2  0.23    0.94      0.90    0.94        0.96

TOTAL      0.68              0.87                0.95

PROGRAM STOP AT 5050

USED      .89 UNITS
```